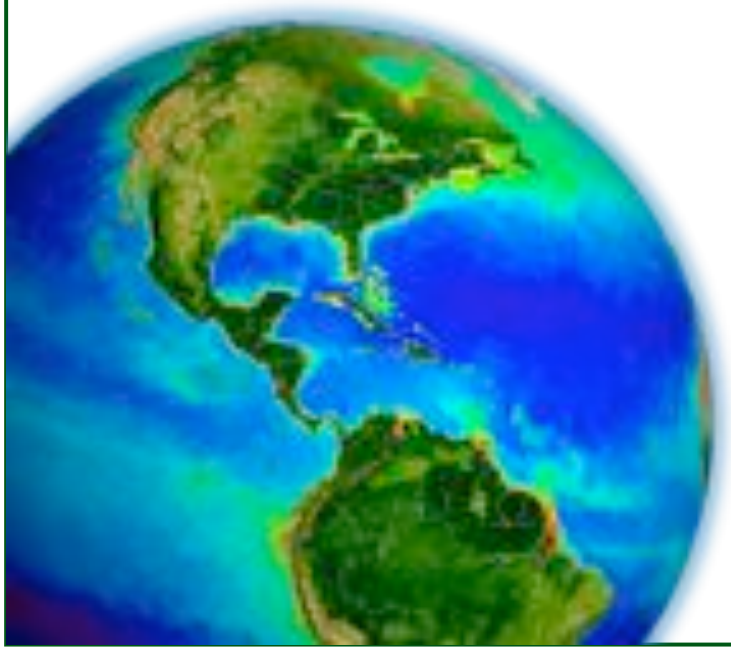
Ocean Color Reprocessing

- Ocean Breakout -



Bryan Franz

and the

Ocean Biology
Processing Group

MODIS Science Team Meeting
January 2010

Ocean Color Reprocessing

Scope: SeaWiFS, MODISA, MODIST, OCTS, CZCS

Status:

- SeaWiFS reprocessing completed November 2009
- MODISA to begin next week, completed in February-March

Highlights:

- sensor calibration updates
- regeneration of all sensor bandpass quantities
- new aerosol models based on AERONET
- improved turbid-water atmospheric correction algorithm
- accounting for atmospheric NO2 absorption
- updated chlorophyll *a* and Kd algorithms based on NOMAD v2
- expanded product suite
- maximizing consistency in all processing phases

Expanded MODIS Product Suite

OLD

- nLw(λ)
- Chlorophyll *a*
- $K_d(490)$
- Ångstrom
- AOT
- Epsilon

NEW

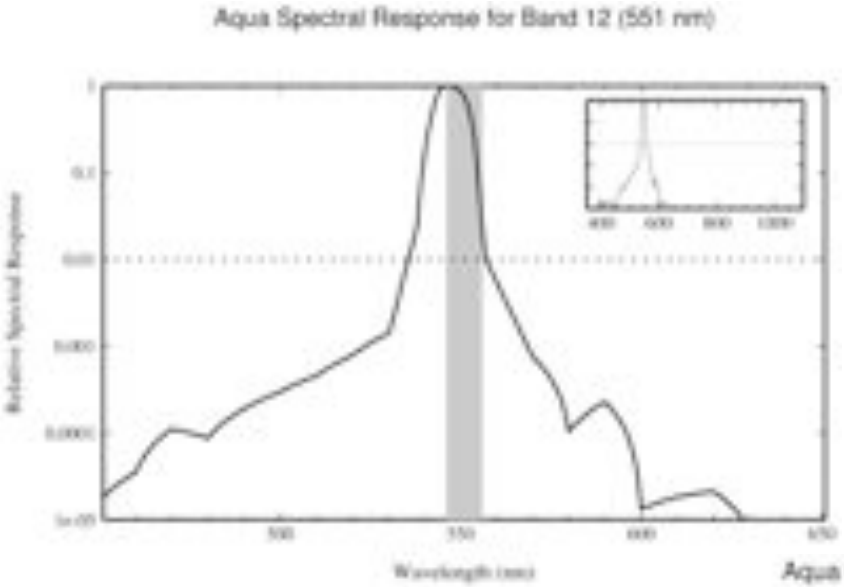
- $R_{rs}(\lambda)$ → $R_{rs}(412)$, $R_{rs}(443)$, $R_{rs}(469)$, $R_{rs}(488)$, $R_{rs}(531)$, $R_{rs}(547)$, $R_{rs}(555)$, $R_{rs}(645)$, $R_{rs}(667)$, $R_{rs}(678)$
- Chlorophyll *a*
- $K_d(490)$
- Ångstrom
- AOT
- POC
- PIC
- CDOM_index
- PAR
- iPAR
- Fluorescence LH
- Fluorescence QY

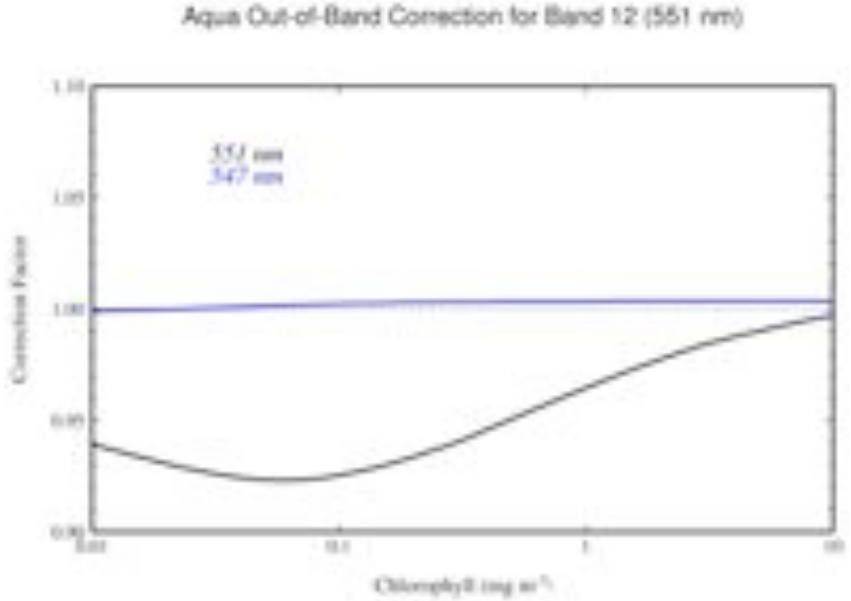
land bands

revised band center

$$R_{rs}(\lambda) = \frac{nL_w(\lambda)}{F_0(\lambda)}$$

Change 551 Band Center to 547



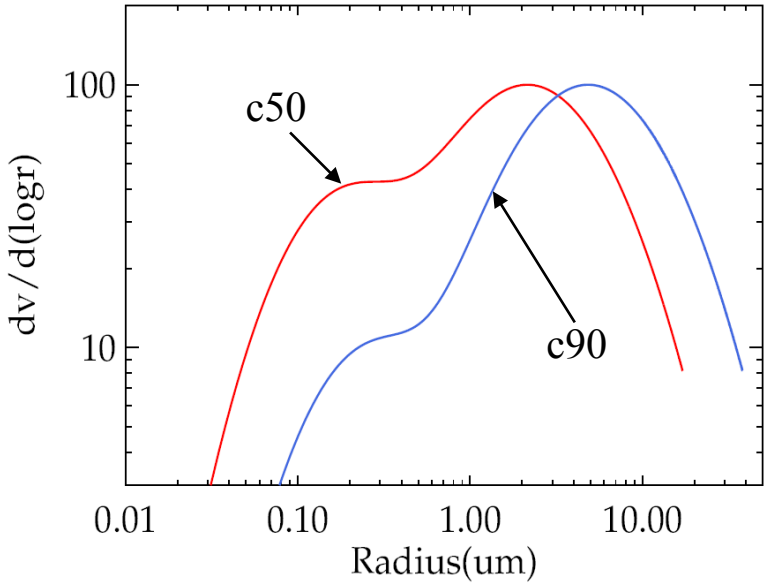


Common Algorithm Changes

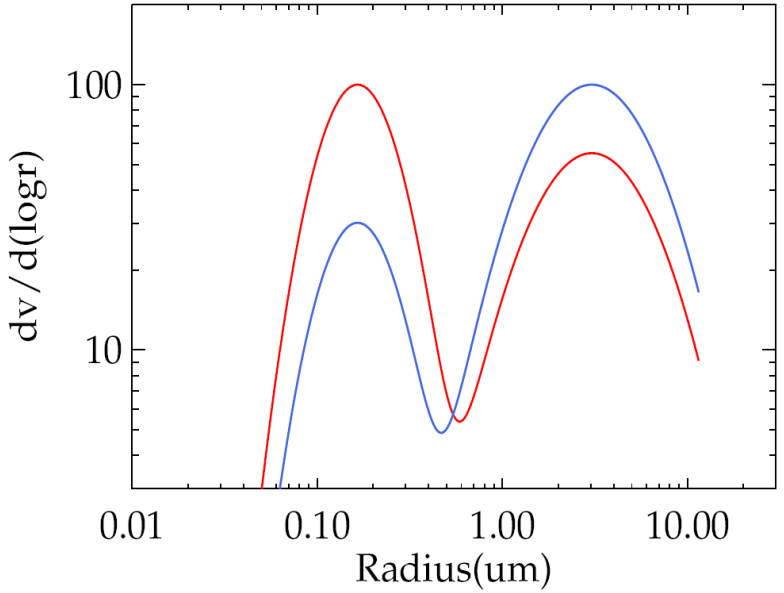
New Aerosol Models

- based on AERONET size distributions & albedos
- vector RT code accounting for polarization (Ahmad-Fraser)
- 80 models (8 humidities x 10 size fractions)
- model selection now descriminated by relative humidity
- revised vicarious calibration assumption (α=0.65 at Tahiti)

Old S&F Size Distributions



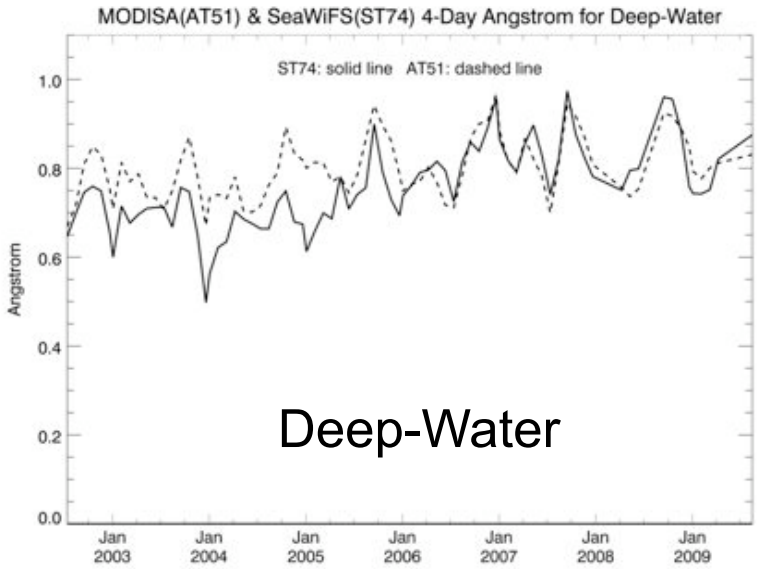
New AERONET-based Size Distributions

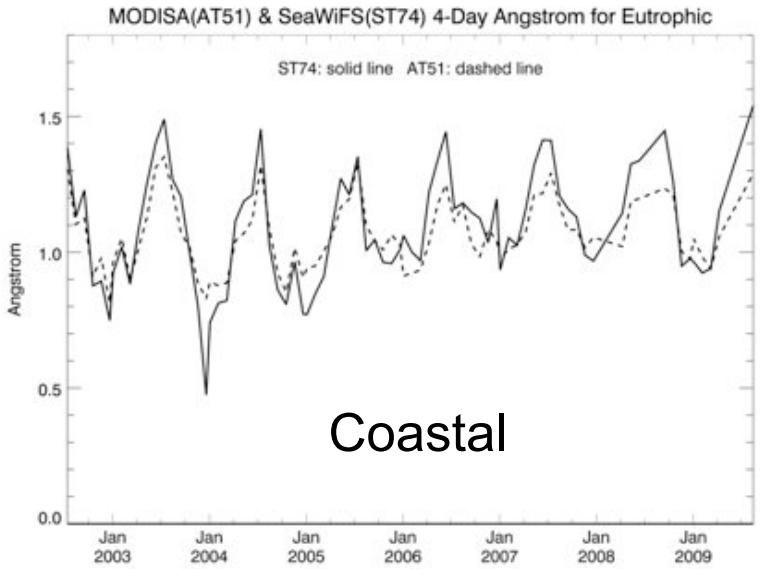


Ahmad, Z., B. A. Franz, C. R. McClain, E. J. Kwiatkowska, J. Werdell, E. Shettle, and B. N. Holben (2010). New aerosol models for the retrieval of aerosol optical thickness and normalized water-leaving radiances from the SeaWiFS and MODIS sensors over coastal regions and Open Oceans (drafted).

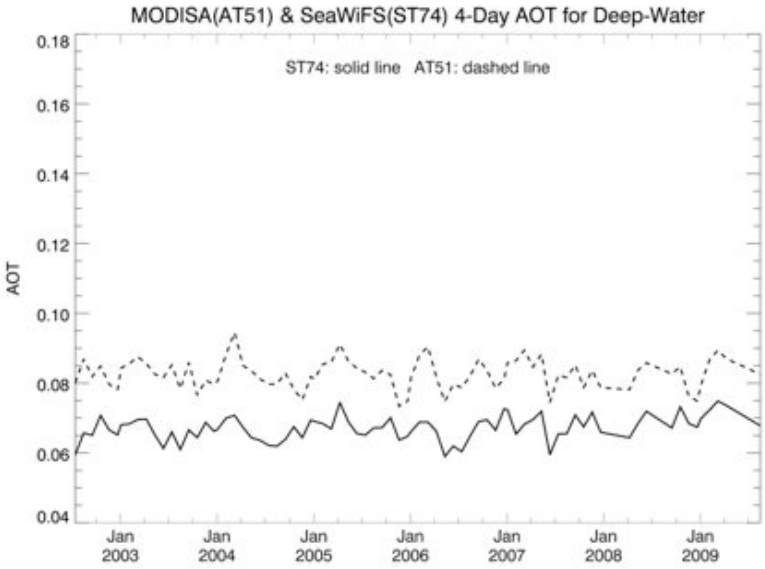
MODISA and SeaWiFS Aerosol Comparison

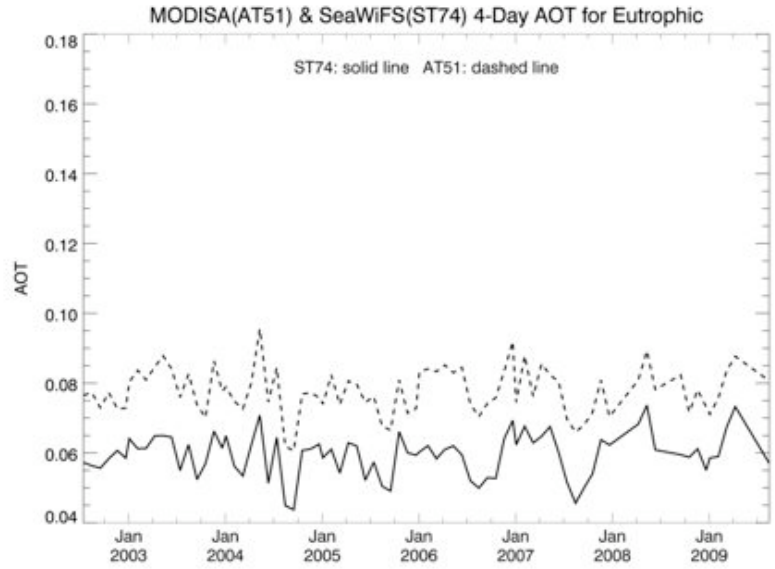
Ångstrom





AOT

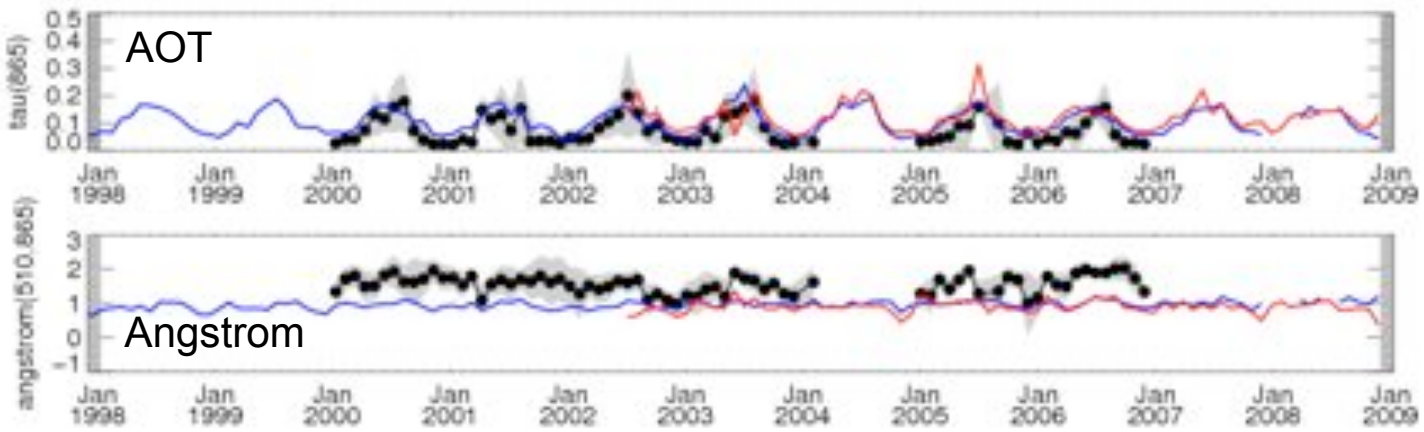




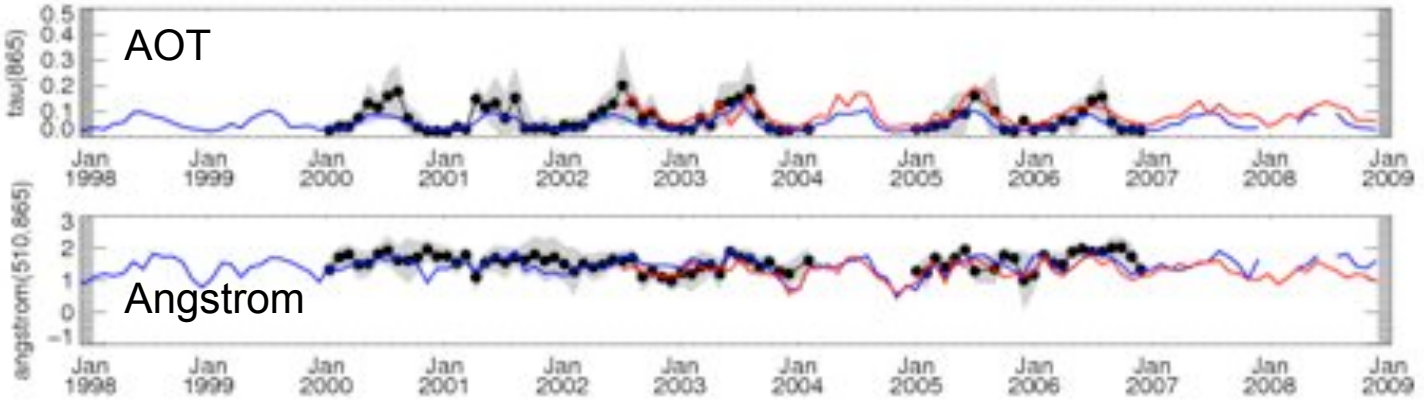
Improved Aerosol Retrievals Relative to AERONET

Upper Chesapeake Bay

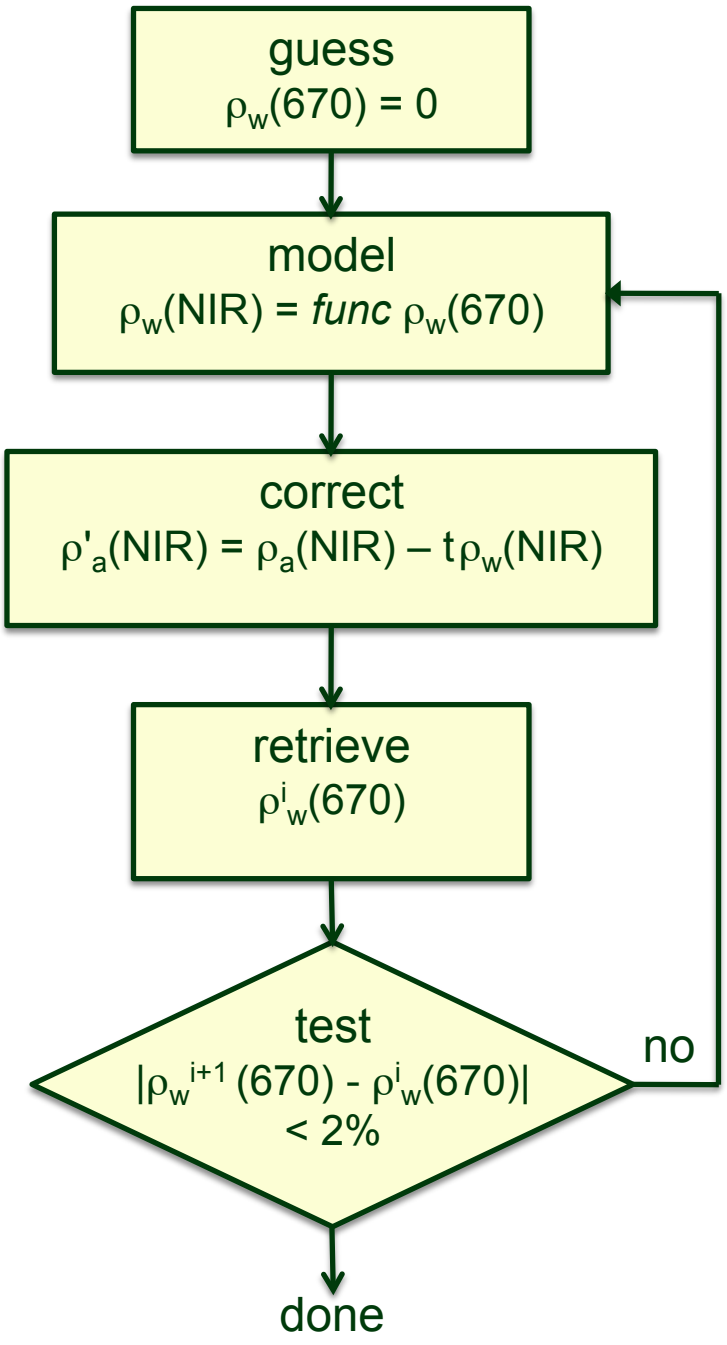
Before



After



SeaWiFS — MODISA • AERONET



Turbid Water Atmospheric Correction: $\rho_w(NIR) \neq 0$

model

1) convert $\rho_w(670)$ to $b_b/(a+b_b)$
via Morel f/Q and retrieved Chl_a

2) estimate $a(670) = a_w(670) + a_{pg}(670)$
via NOMAD empirical relationship

$$a(670) = e^{\left(\ln(C_a)*0.9389-3.7589\right)} + a_w(670)$$

3) estimate $b_b(NIR) = b_b(670)\ (\lambda/670)^{\eta}$
via Lee 2010

$$\eta = 2.0 * \left[1. - 1.2 * e^{(-0.9*R_{rs}(443)/R_{rs}(555))}\right]$$

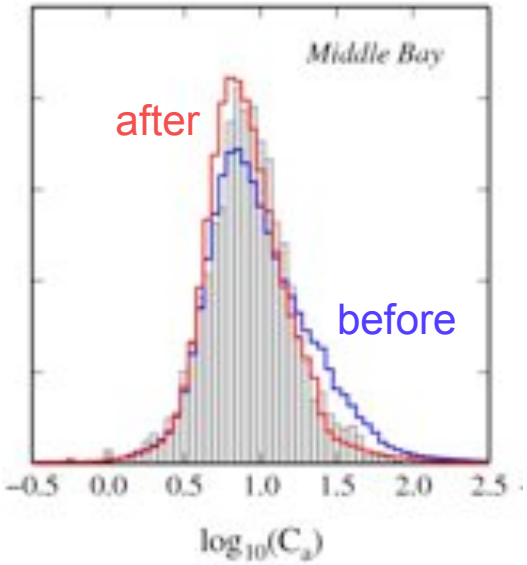
4) assume $a(NIR) = a_w(NIR)$

5) estimate $\rho_w(NIR)$ from $b_b/(a+b_b)$
via Morel f/Q and retrieved Chl_a

Revised Turbid-Water Atmospheric Correction

- atmospheric correction in high-scattering water requires an iterative procedure to model and remove the water contribution in the NIR

- bio-optical model updated, and results substantially improved

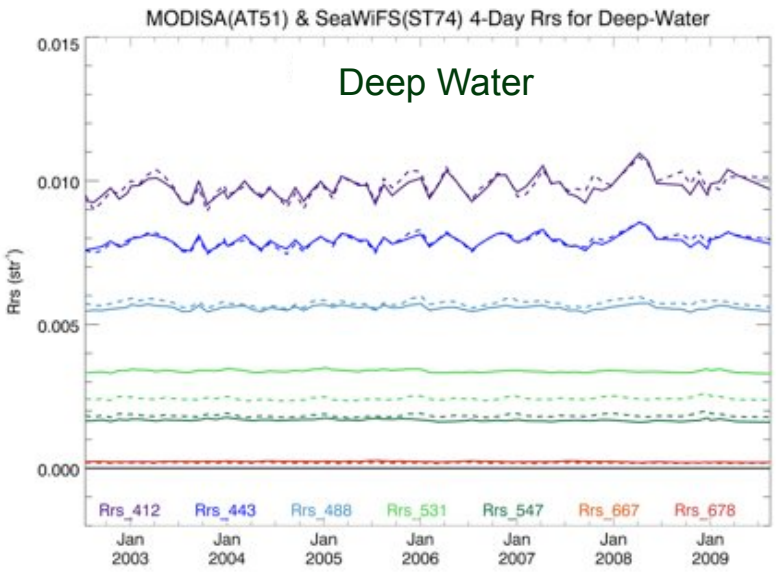


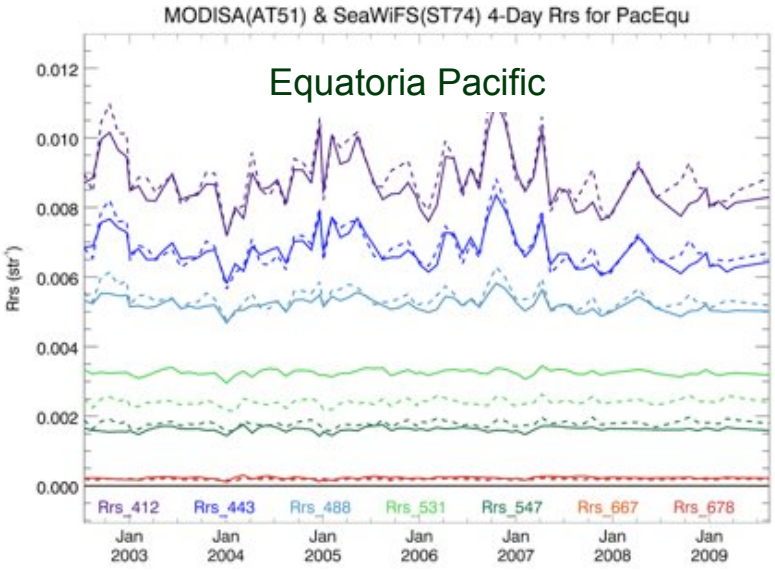
Bailey, S.W.., Franz, B.A., and Werdell, P.J. (2010). Estimation of near-infrared water leaving reflectance for satellite ocean color data processing, Opt. Exp., submitted.

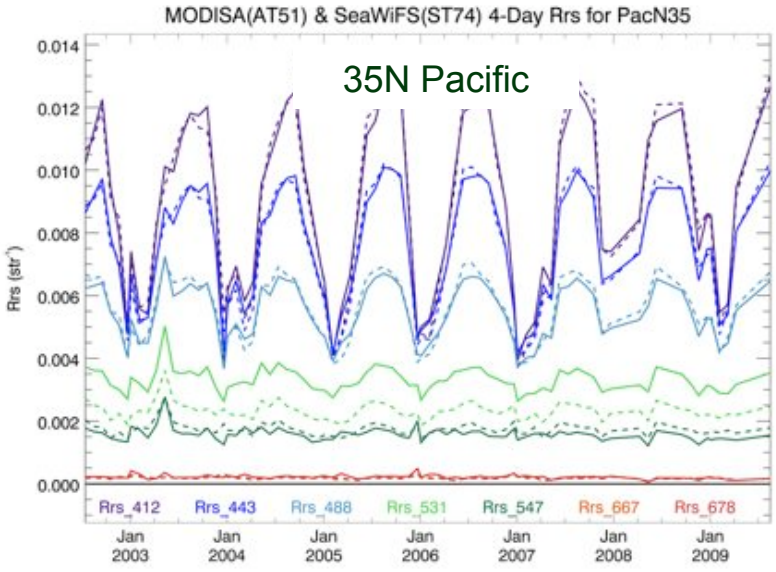
Global Results

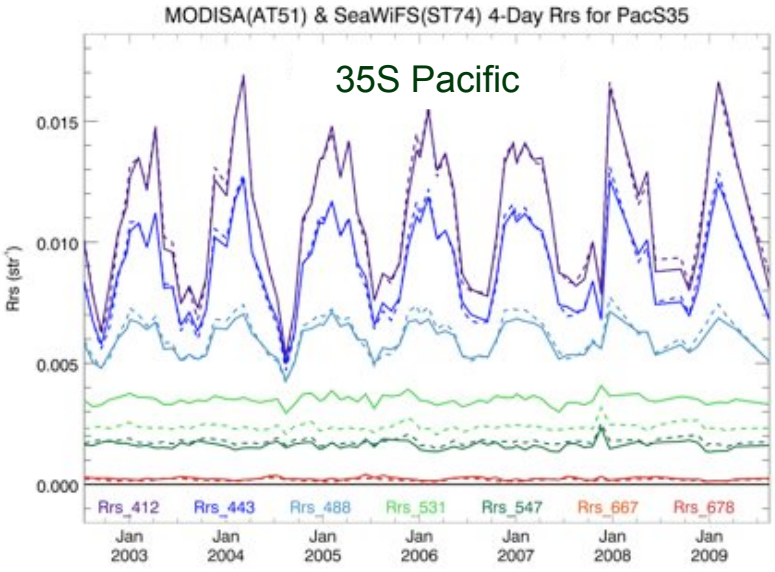
Good Agreement in Water-Leaving Reflectance

over duration of SeaWiFS and MODISA mission overlap

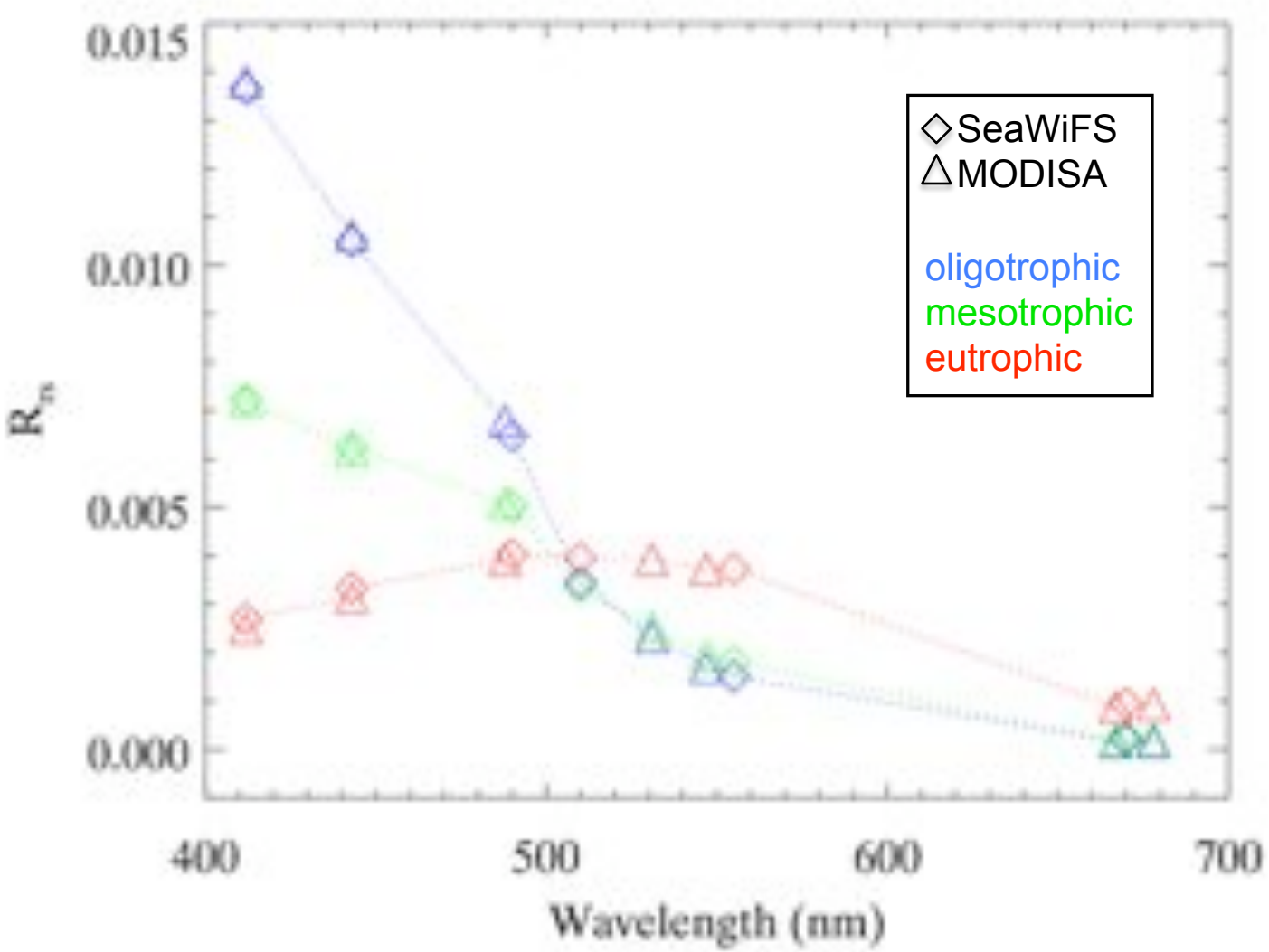








Mean Spectral Differences Agree With Expectations

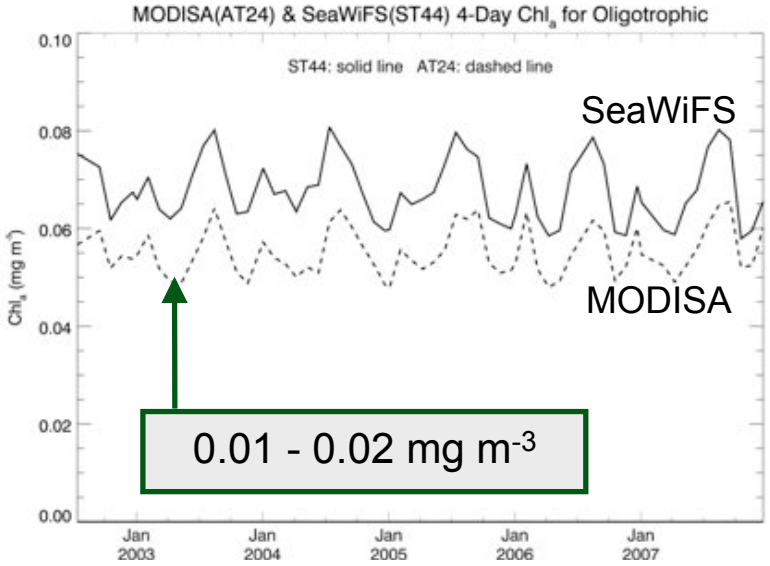


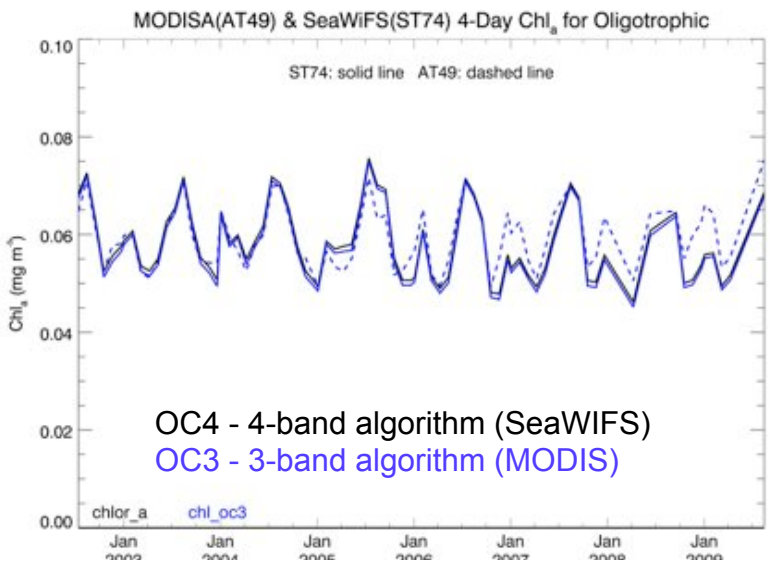
Much Improved Agreement in Clear-Water Chl_a

Before

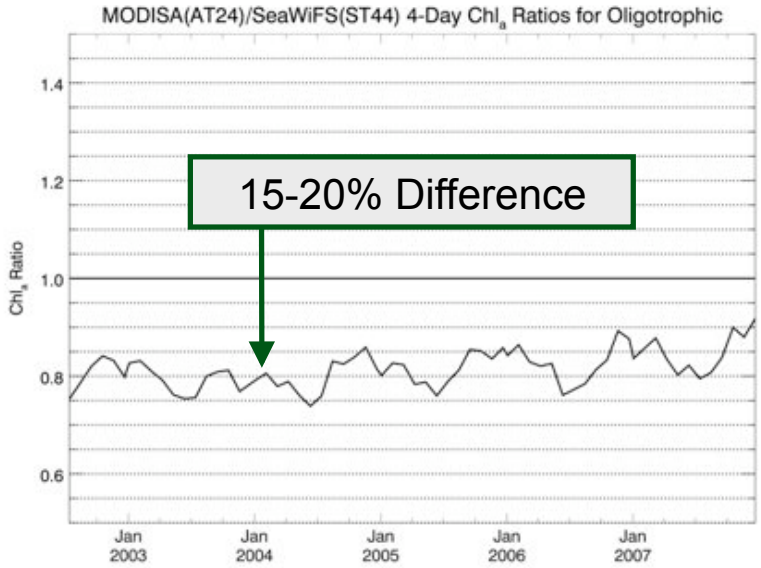
After

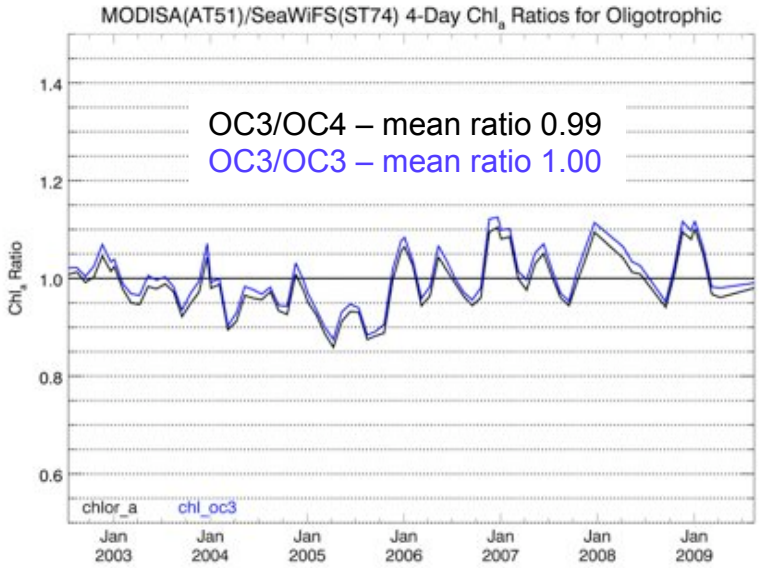
Comparison



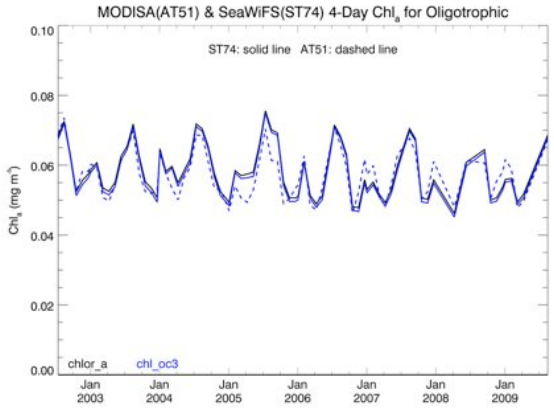
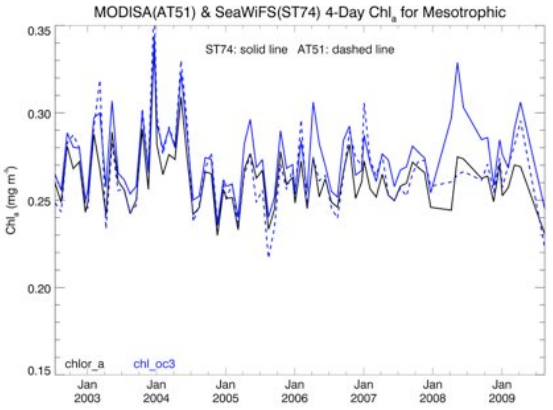
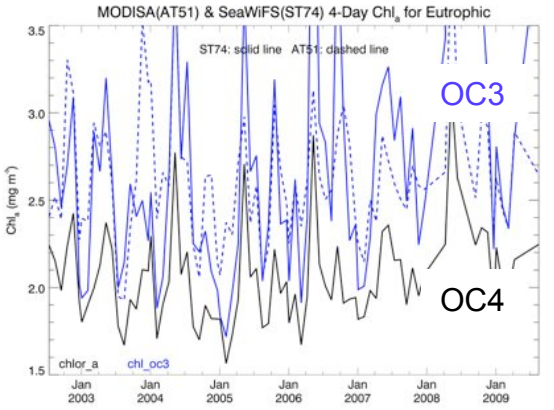
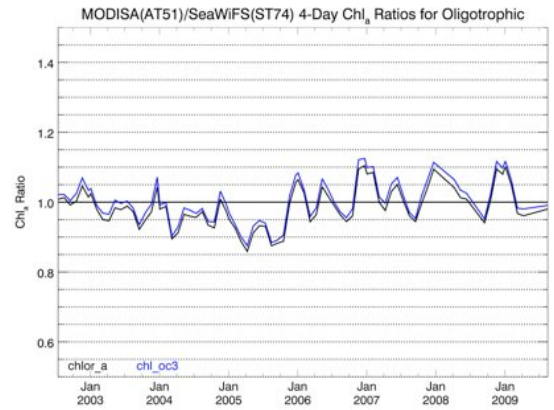
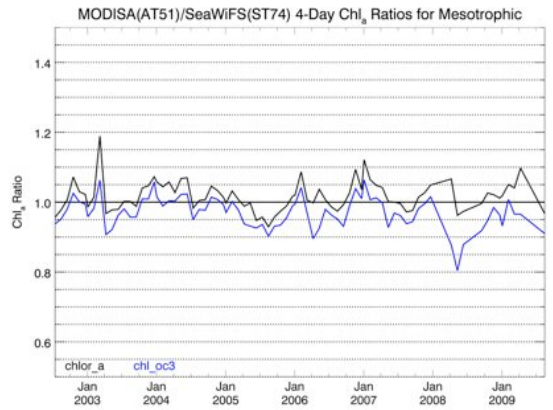
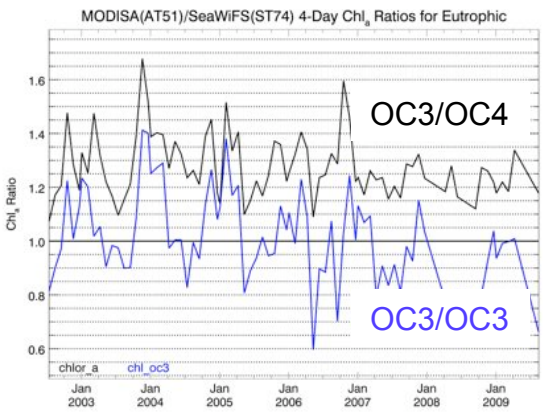


Ratio





MODISA and SeaWiFS Chl_a Comparison

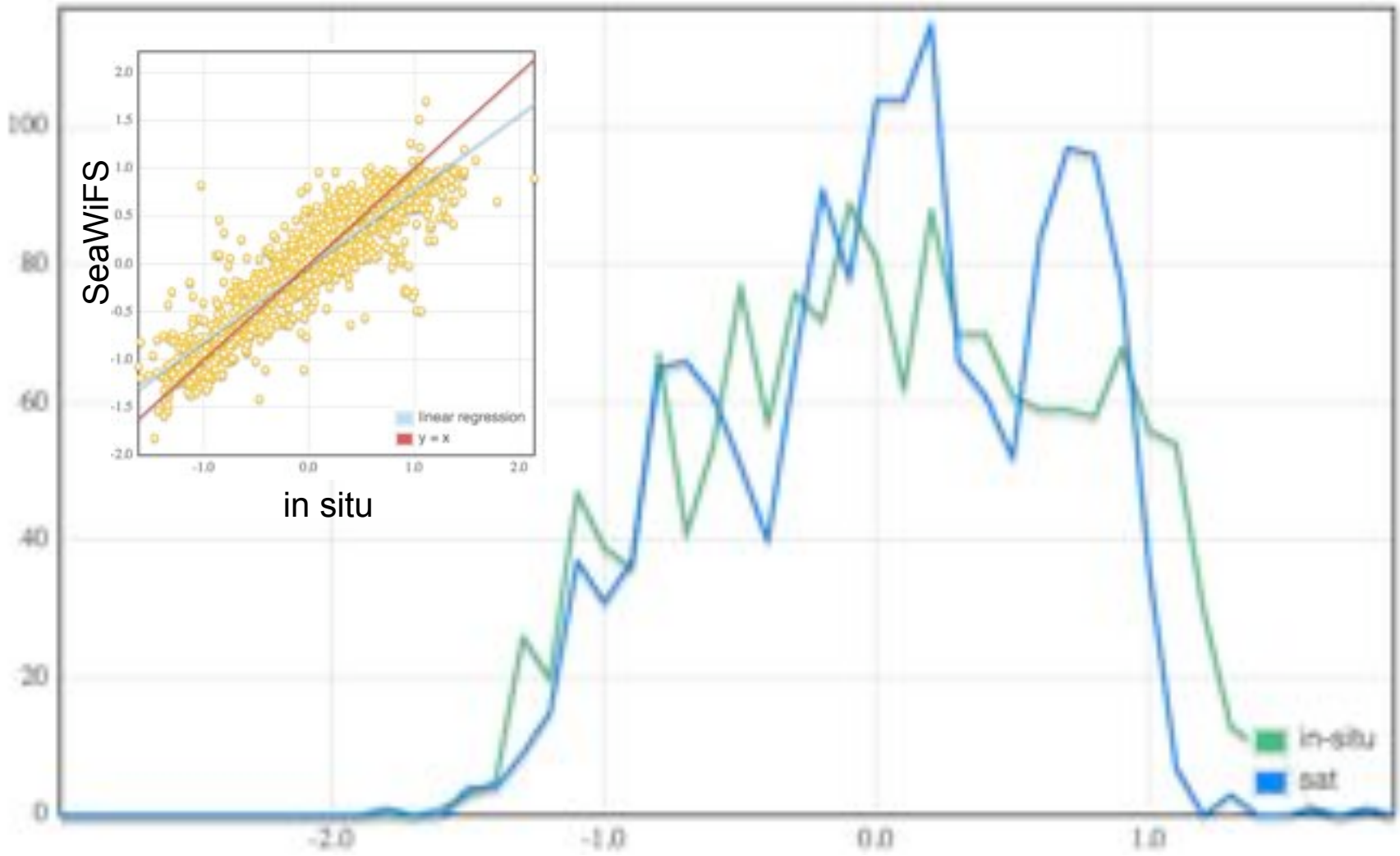
	Oligotrophic	Mesotrophic	Eutrophic
Comparison			
Ratio			

<Ratio>	Std Dev
0.99	0.058
1.00	0.060

<Ratio>	Std Dev
1.02	0.042
0.97	0.045

<Ratio>	Std Dev
1.28	0.12
1.01	0.17

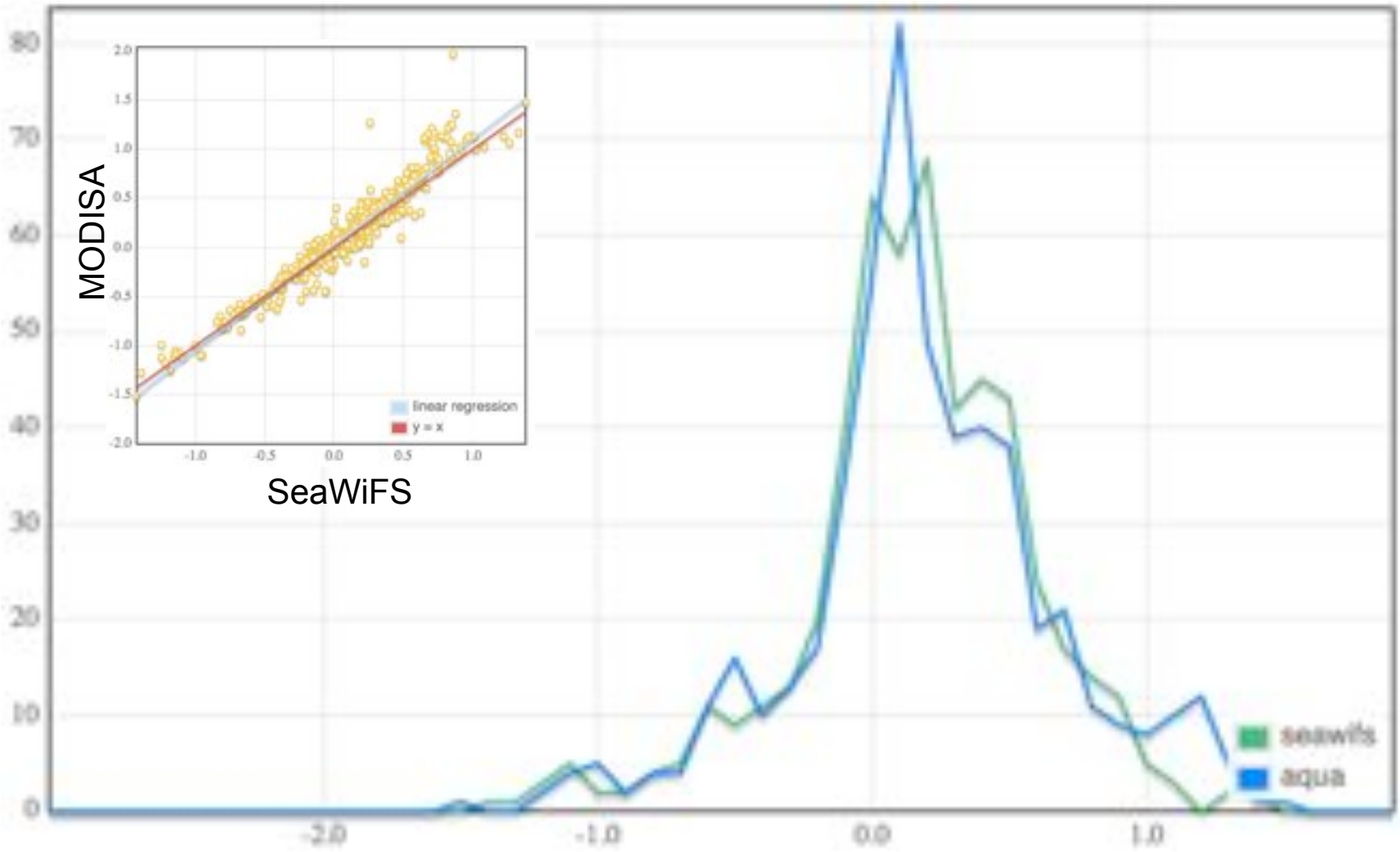
SeaWiFS Chl_a: Good Agreement with Global In situ



In-Situ Range	Sat Range	N	Slope	Intercept	R Squared	Median Ratio	Abs % Difference
(-1.61979, 2.14003)	(-1.81612, 1.70704)	1560	0.79275	-0.0152278	0.81477005	0.98005764	36.67182

MODISA vs SeaWiFS Chl_a

at common in situ match-up locations



seawifs Range	aqua Range	N	Slope	Intercept	R Squared	Median Ratio	Abs % Difference
(-1.42248, 1.38101)	(-1.51267, 1.96563)	526	1.07836	0.0247077	0.92288022	1.0608265	13.805507

next steps: MODIST

- Well documented issues with radiometric stability:
  - Franz, B.A., E.J. Kwiatkowska, G. Meister, and C. McClain (2008). Moderate Resolution Imaging Spectroradiometer on Terra: limitations for ocean color applications, J. Appl. Rem. Sens., 2, 023525.

- Vicarious on-orbit recharacterization of RVS and polarization:
  - Kwiatkowska, E.J., B.A. Franz, G. Meister, C. McClain, and X. Xiong (2008). Cross-calibration of ocean-color bands from Moderate Resolution Imaging Spectroradiometer on Terra platform, Appl. Opt., 47 (36).

- Analysis to be repeated and results fully implemented once SeaWiFS and MODISA reprocessing is completed.

next steps: OCTS, CZCS

- Algorithms will be updated for consistency with SeaWiFS and MODIS, and missions will be reprocessed.

Summary

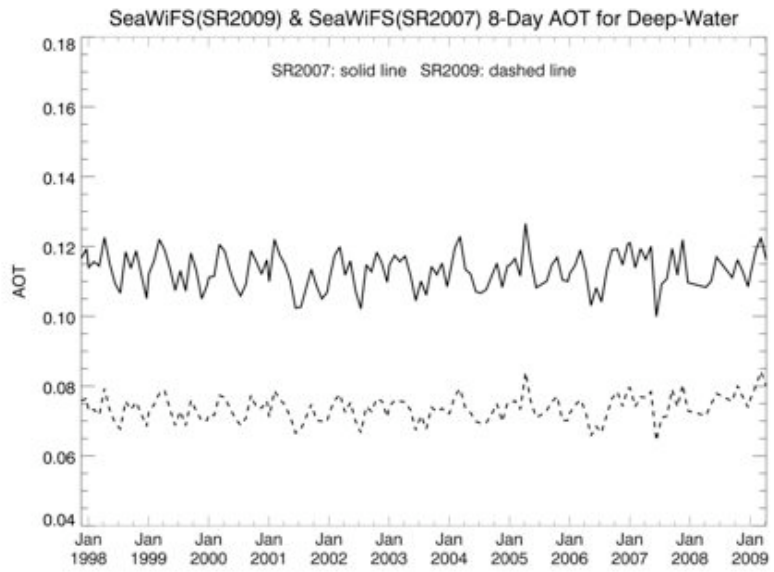
- AERONET-based aerosol models: improved agreement between satellite and in situ aerosol optical properties.
- Revised turbid-water atmospheric correction: improved agreement between satellite and in situ Chl_a in high-scattering waters.
- Updated SeaWiFS and MODISA calibrations: improved temporal stability in Rrs trends, MODISA fluorescence trend.
- Remaining issues with MODISA temporal drift in blue bands corrected through vicarious characterization of RVS shape changes.
- Consistency of algorithms and calibrations: much improved agreement between MODISA and SeaWIFS ocean color retrievals.
- Long-standing mission-to-mission differences in oligotrophic chlorophyll resolved: mean differences reduced from 15-20% to 1-2%.

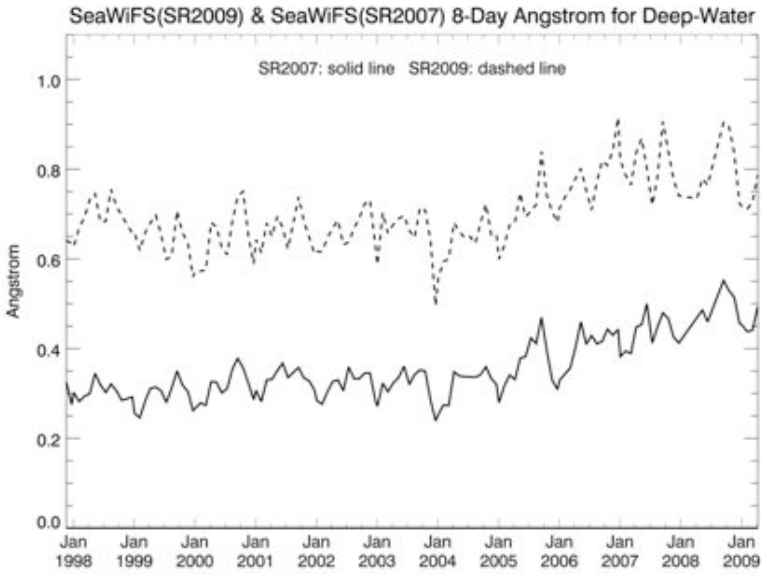
http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/


Thank You
http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/

Back-up

Effect of Aerosol Changes





Impact of:

- new aerosol models
- revised model selection scheme
- revised NIR vicarious calibration
- SeaWIFS straylight masking

For open ocean retrievals:

- reduced the AOT
- doubled the Ångstrom

Good Agreement in Water-Leaving Reflectance

over duration of mission overlap

Global Mean
Common Mission

	SeaWIFS		MODISA		Ratio (M/S)	
Prod	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Rrs_412	0.00911	0.00039	0.00913	0.00041	1.00333	0.02142
Rrs_443	0.00749	0.00023	0.00748	0.00027	0.99816	0.01340
Rrs_490,Rrs_488	0.00545	0.00010	0.00559	0.00013	1.02562	0.01122
Rrs_510,Rrs_531	0.00342	0.00005	0.00253	0.00006	0.74070	0.01348
Rrs_555,Rrs_547	0.00182	0.00005	0.00196	0.00005	1.08110	0.02570
Rrs_670,Rrs_667	0.00027	0.00002	0.00022	0.00001	0.81749	0.04691
Rrs_670,Rrs_678	0.00027	0.00002	0.00024	0.00002	0.89022	0.04923

- Reflectances in very good agreement at common wavelengths
- Spectral differences consistent with expectation
  - except 670, a SeaWiFS S/N issue

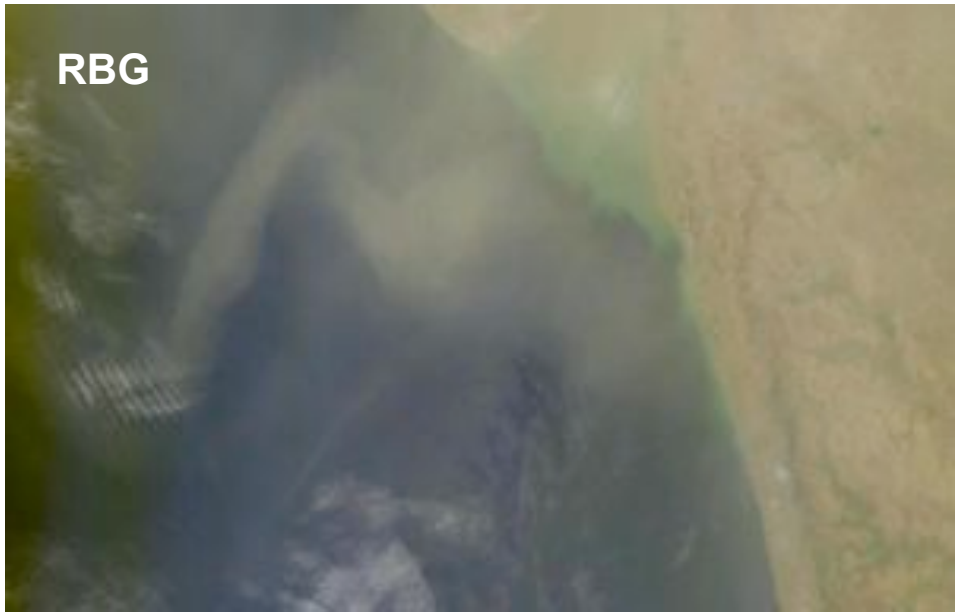
International Collaborations

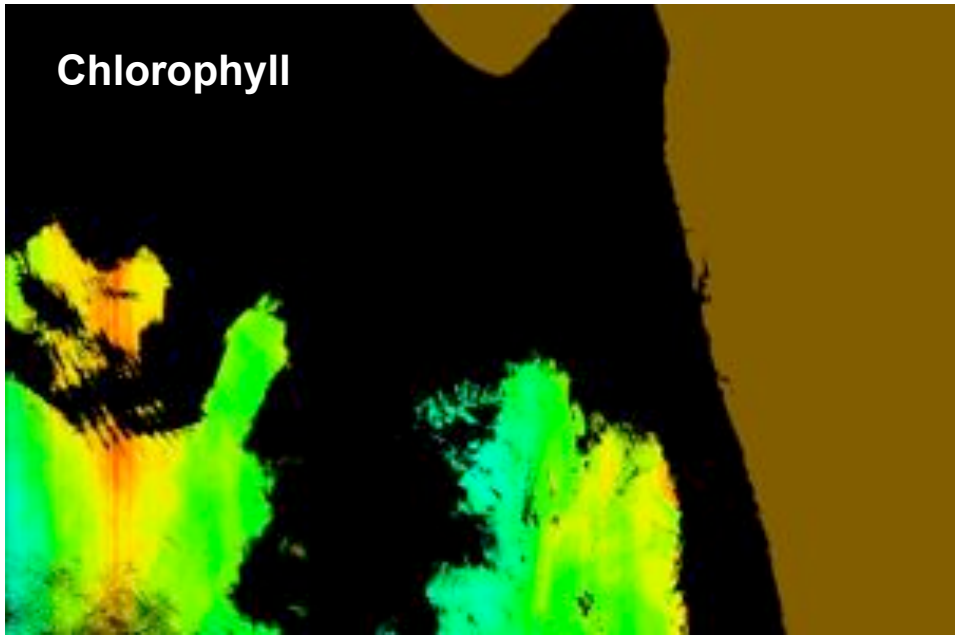
ISRO-NOAA-NASA Collaborations on OCM-2

- Letter of Intent and Proposed Responsibilites signed 18 November 2009.
- ISRO to provide online access to global OCM-2 data (4km) at Level-1B for research use, to all international users, at no cost.
- NASA to provide processing capability (Level-1B through Level-3) for use by ISRO and the international community (distr. in SeaDAS).
  - preliminary capability based on OCM already implemented
  - need ISRO to finalize Level-1B format
- NASA & NOAA to participate in Joint Cal/Val Team

Preliminary OCM-2 Level-1B format , simulated from OCM-1.

Sample OCM processing via NASA software and common SeaWiFS/MODIS algorithms.

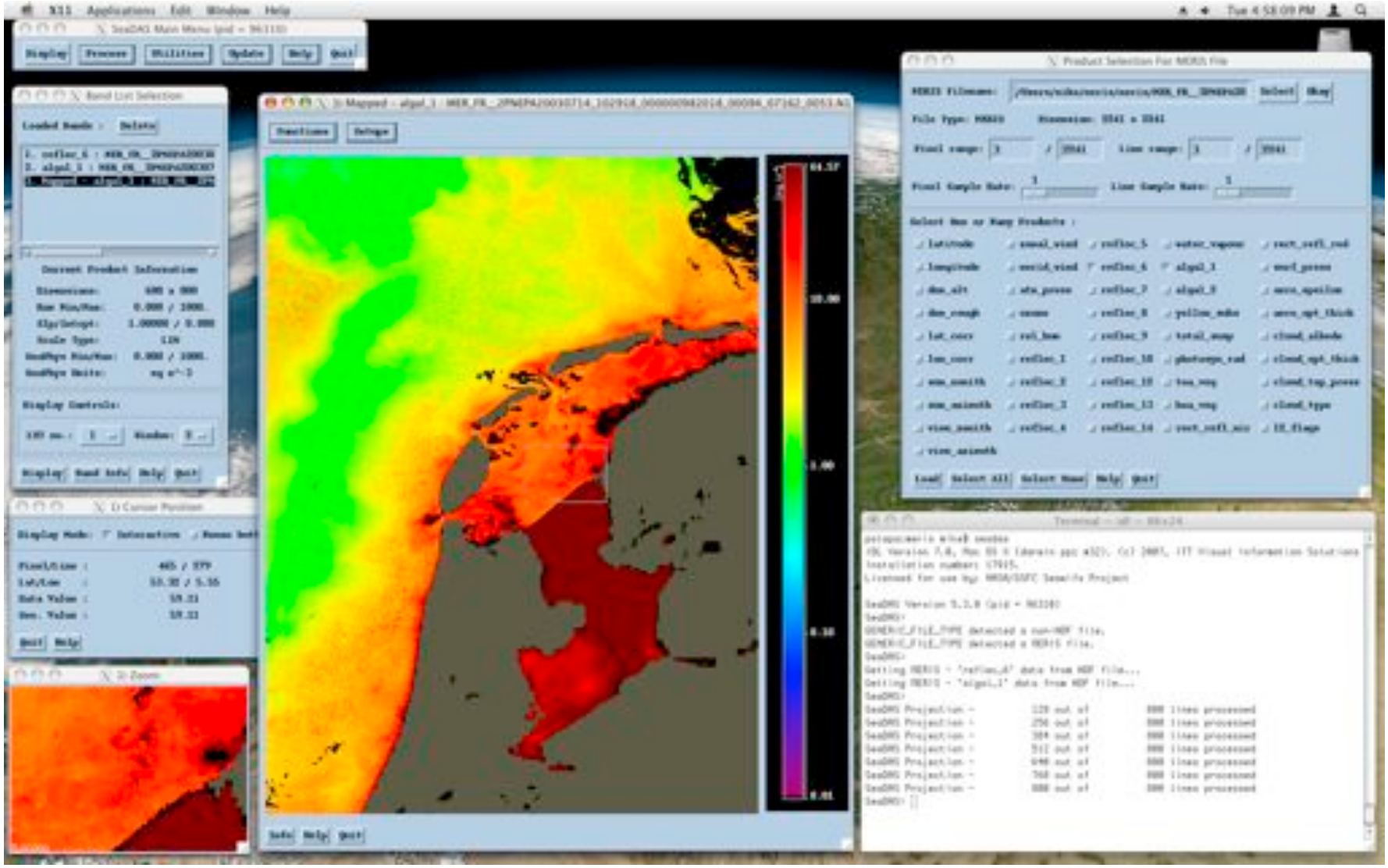




ESA/NASA MERIS Collaborations

- Bryan Franz and Gerhard Meister are now participating members of the MERIS Quality Working Group.
- SeaDAS has been enhanced to support display and analysis of standard MERIS Level-2 products.
- MERIS processing capability has been incorporated into NASA software and released in SeaDAS.

MERIS Level-2 Displayed in SeaDAS

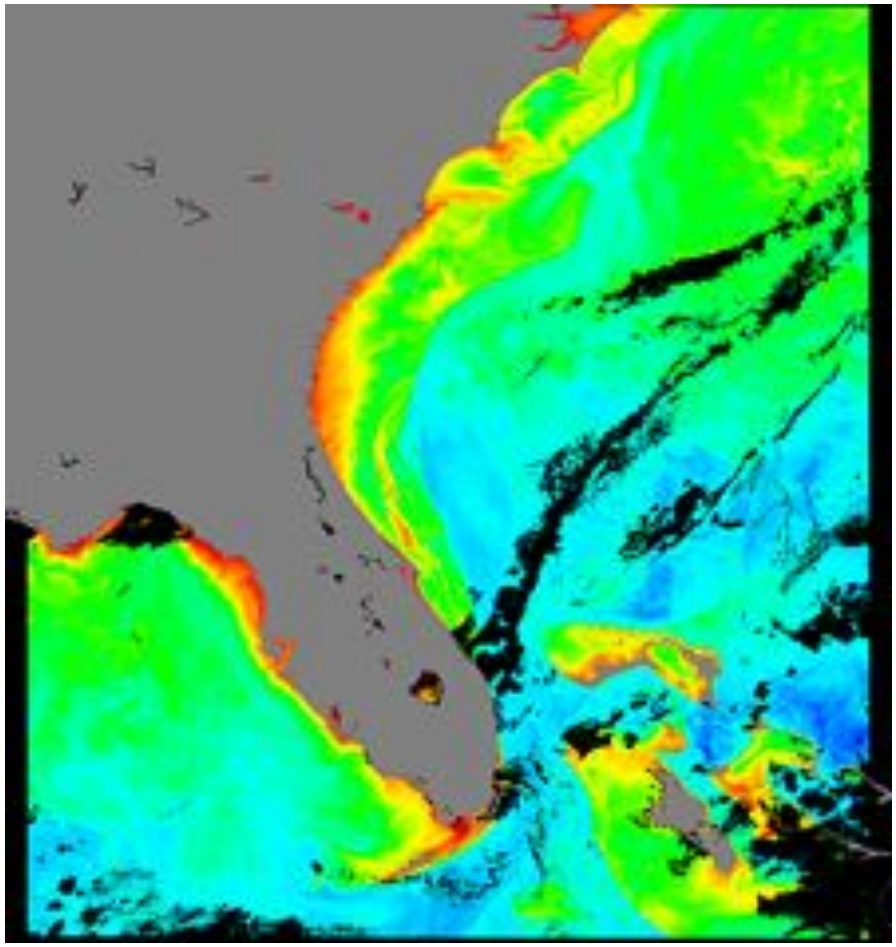


current distributed version supports Level-2 RR data
current development version supports Level-1 and Level-2, RR, FR, and FRS data

MERIS FRS Processed with NASA OC Algorithms

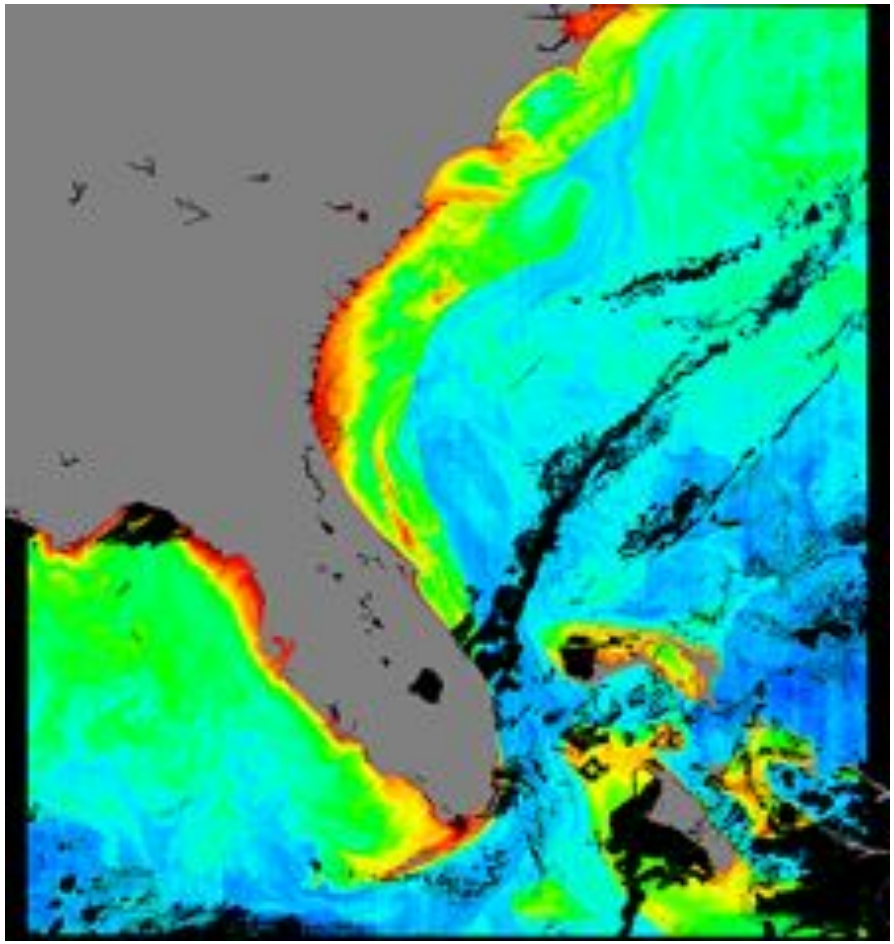
RGB

OC4 Chlorophyll

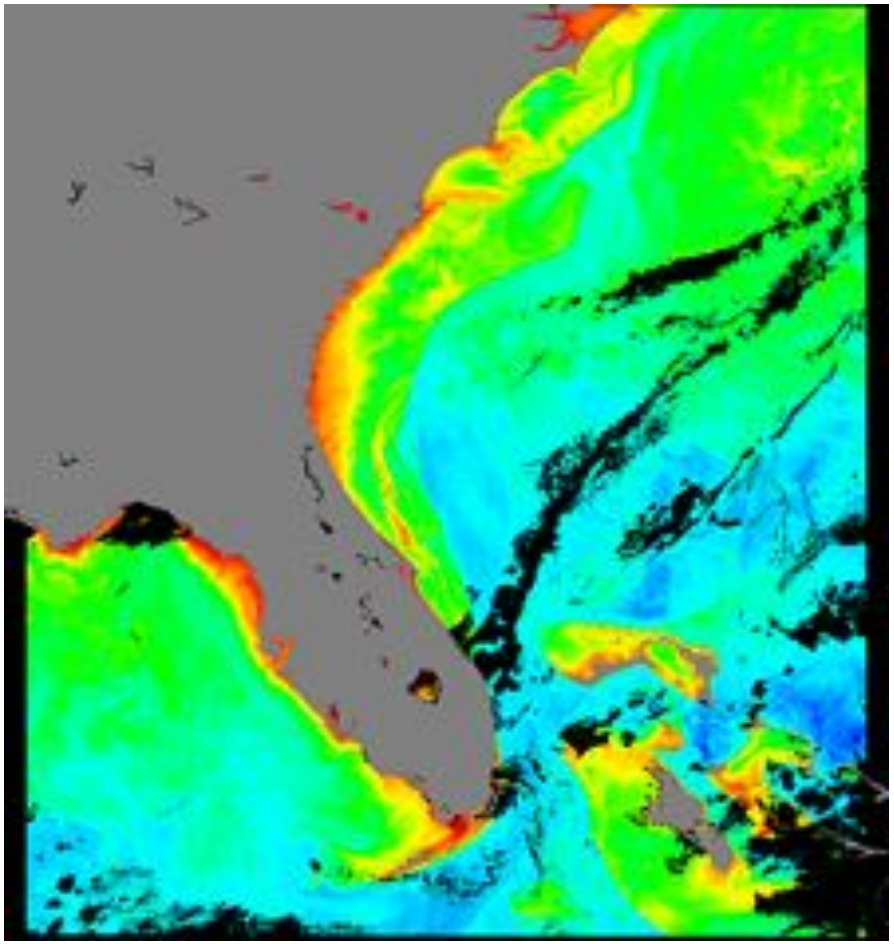


MERIS Processing Comparison

MERIS Algal1 (ESA/Kiruna)



MERIS OC4 (NASA/OBPG)



MODIS Calibration

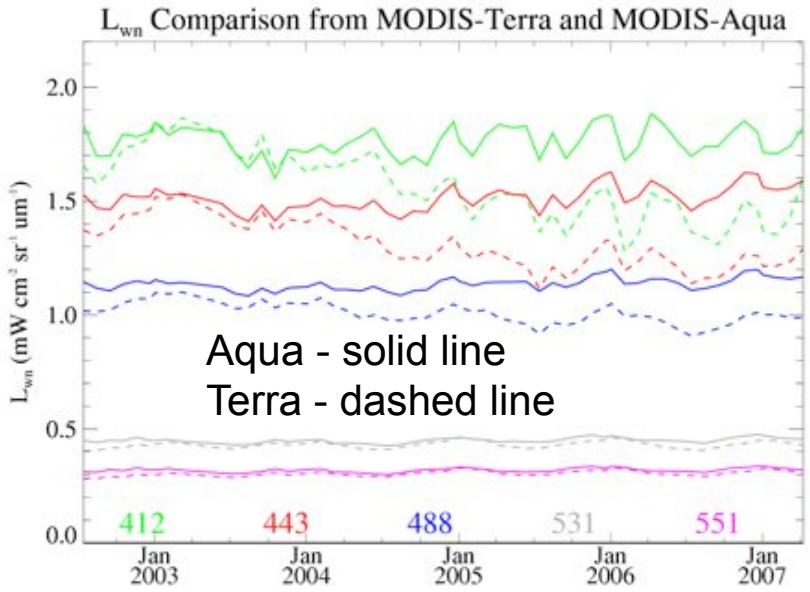
Recovering MODIST for OC: The Problem

- Overheating event in pre-launch testing "smoked" the mirror
  - pre-launch characterization may not adequately represent at-launch configuration (mirror-side ratios, RVS, polarization sensitivities)
- Substantial temporal degradation of instrument response
  - degradation varies with mirror-side and scan-angle
  - temporal change in polarization sensitivity, RVS
- On-board calibration capabilities (lunar, solar) CANNOT assess
  - changes in polarization sensitivities, or
  - changes in RVS “shape”
- Vicarious on-orbit recharacterization required

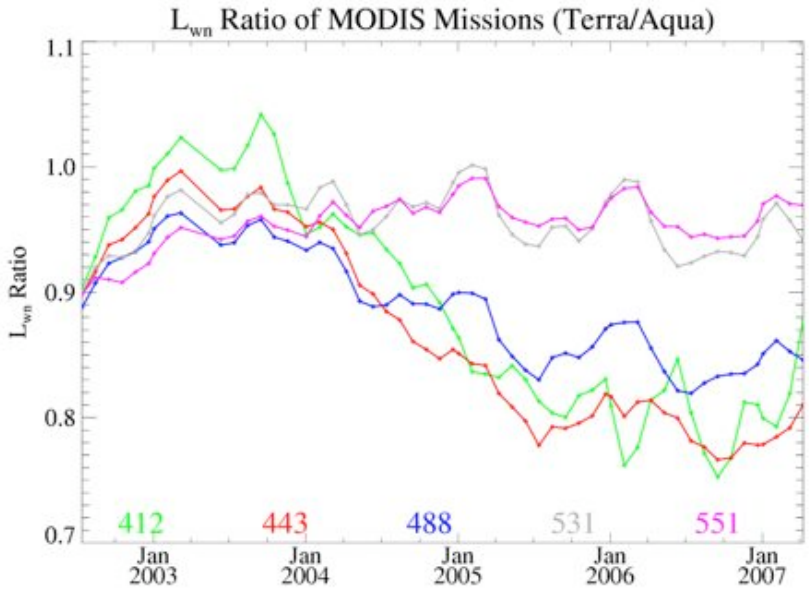
MODIS/Aqua vs MODIS/Terra "as-is"

Temporal Trends in Global Deep-Water nLw

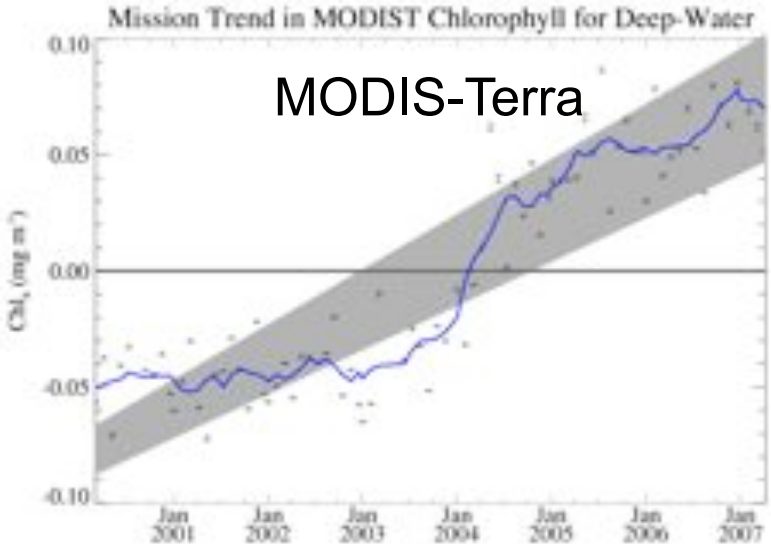
MODIST & MODISA

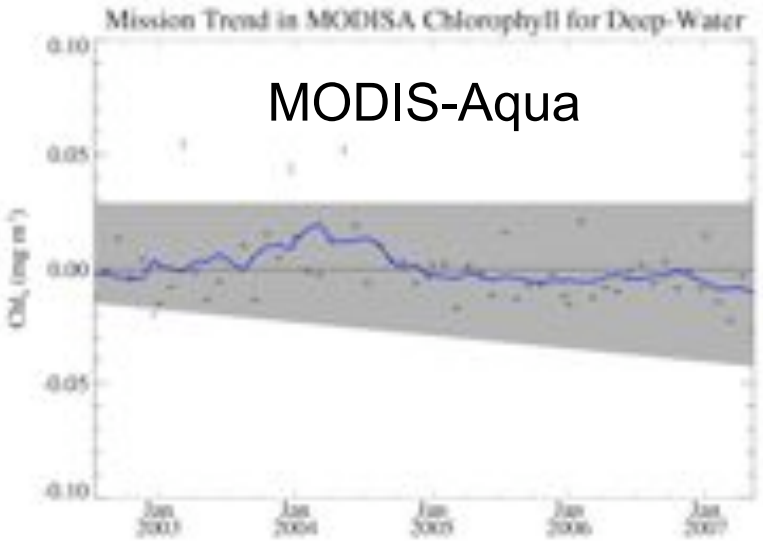


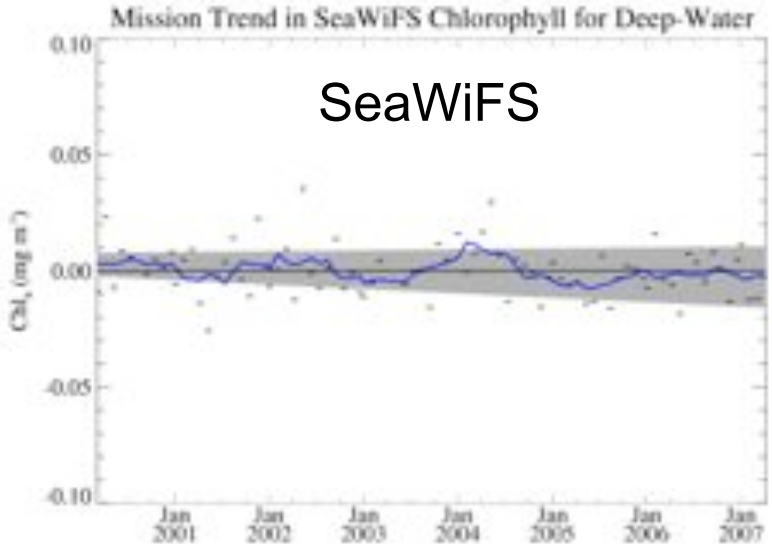
MODIST / MODISA

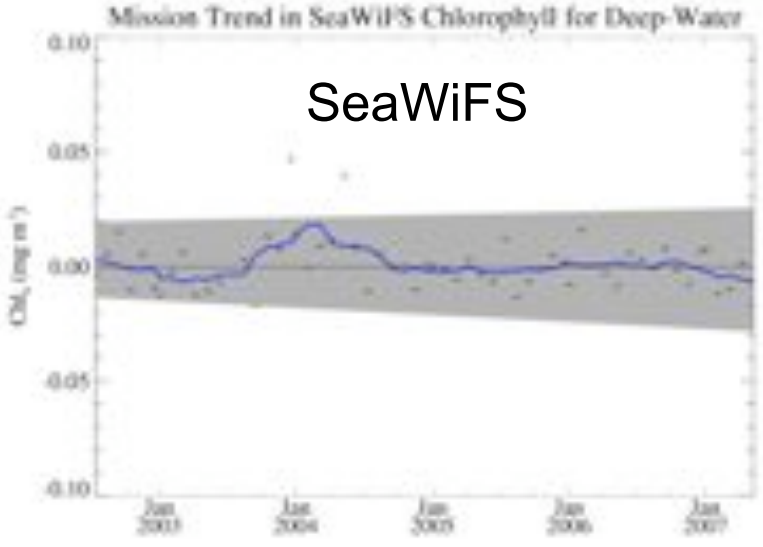


Deep-Water Seasonal Anomaly in Chlorophyll







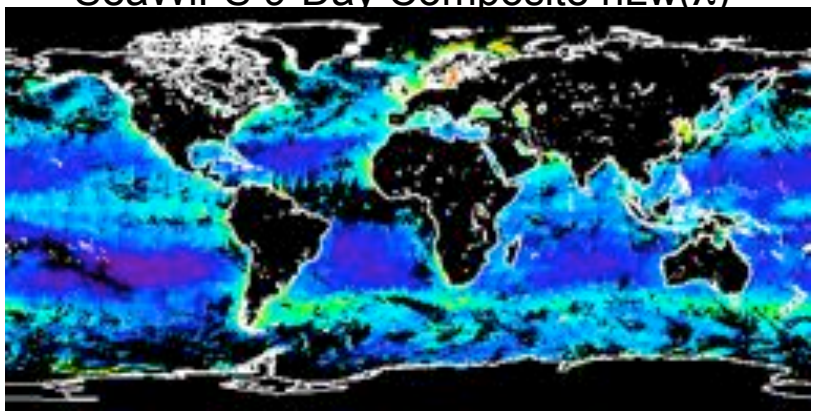


Recovering MODIS/Terra for Ocean Color Use

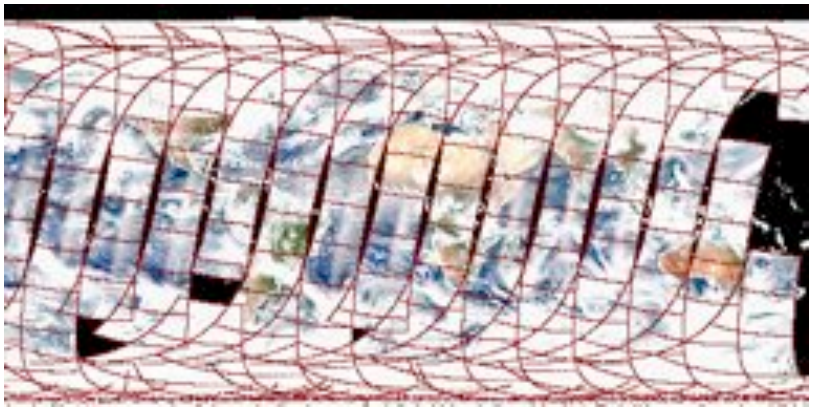
on-orbit characterization of instrument RVS and polarization

$$L_m(\lambda) = \mathbf{M_{11}} L_t(\lambda) + \mathbf{M_{12}} Q_t(\lambda) + \mathbf{M_{13}} U_t(\lambda)$$

SeaWiFS 9-Day Composite nLw(λ)



MODIS Observed TOA Radiances



Vicarious calibration:

given $L_w(\lambda)$ and MODIS geometry, we can predict $L_t(\lambda)$

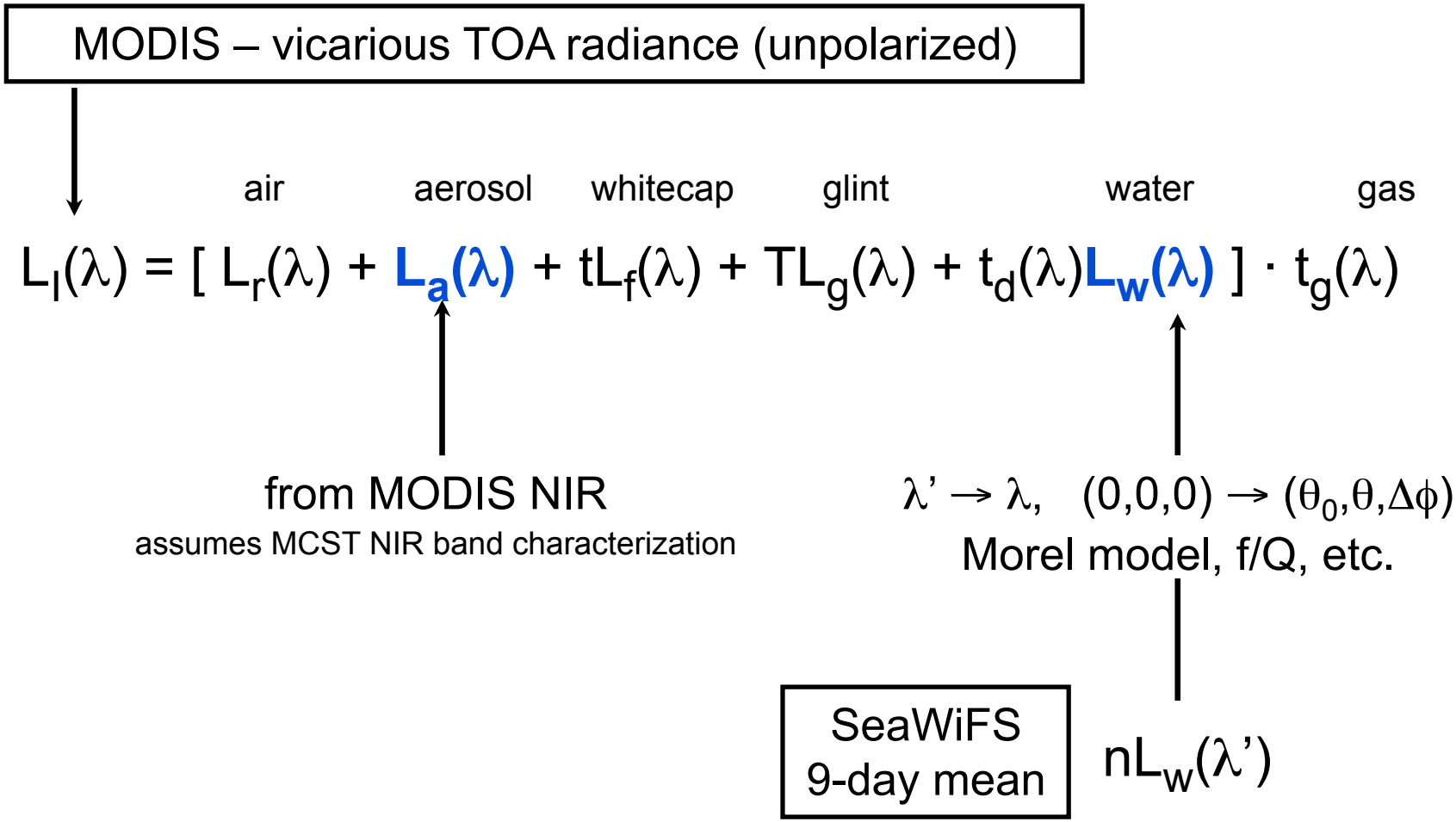
Global optimization:

find best fit M_{11}, M_{12}, M_{13} to relate $L_m(\lambda)$ to $L_t(\lambda)$

where M_{xx} = fn(mirror aoi)

per band, detector, and m-side

Vicarious Characterization of RVS and Polarization



Vicarious Characterization of RVS and Polarization

MODIS – vicarious TOA radiance (unpolarized)

air aerosol whitecap glint water gas

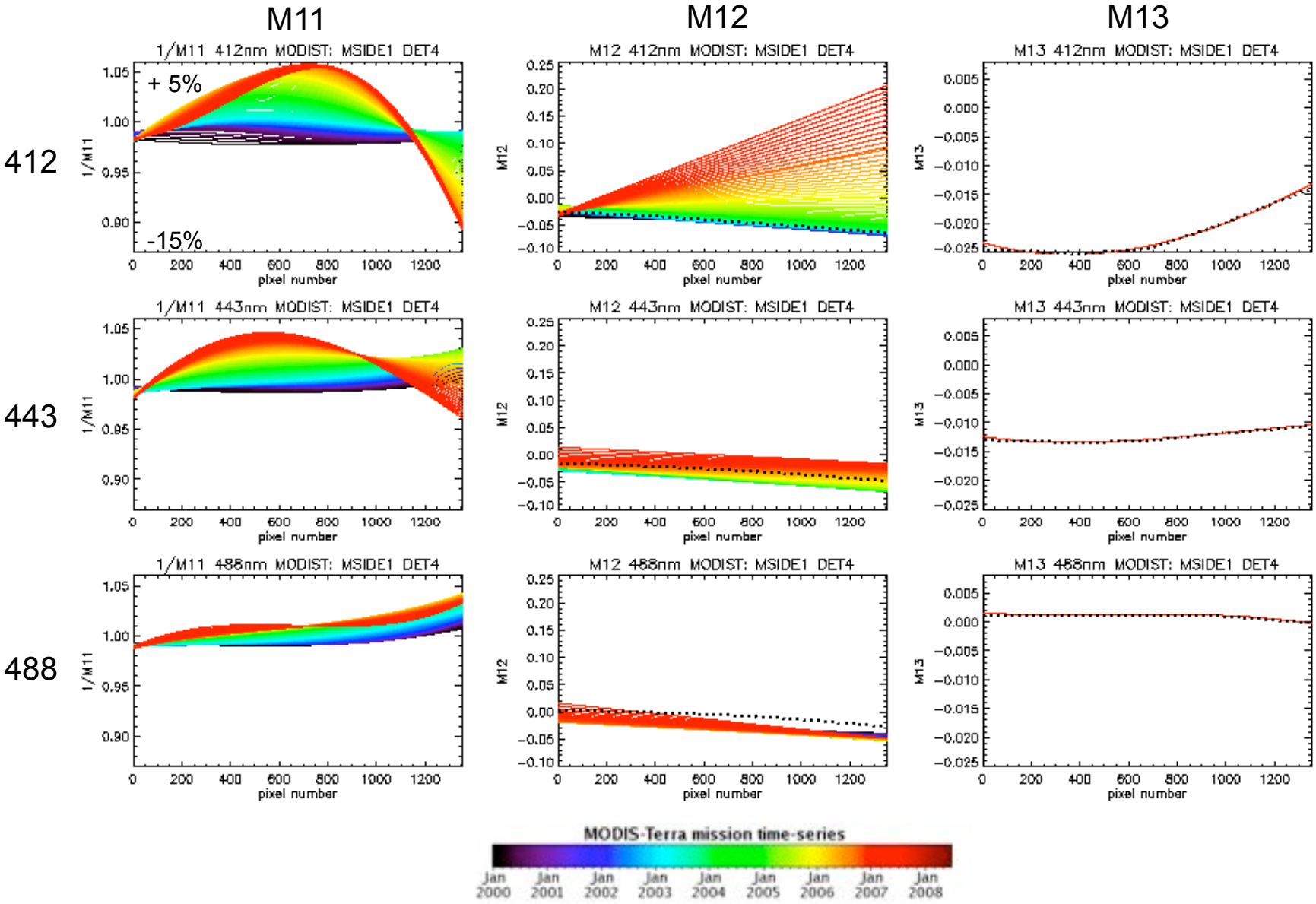
$$L_l(\lambda) = [\, L_r(\lambda) + \mathbf{L_a(\lambda)} + tL_f(\lambda) + TL_g(\lambda) + t_d(\lambda)\mathbf{L_w(\lambda)} \,] \cdot t_g(\lambda)$$

$$\sum L_t(\lambda) - [M_{11}L_l(\lambda) + M_{12}L_Q(\lambda) + M_{13}L_U(\lambda)]$$

minimize over global distribution of path geometries to find best M_{11}, M_{12}, M_{13} per band, detector, and mirror-side

do this for one day per month over the mission lifespan

MODIS-Terra Vicarious Characterization

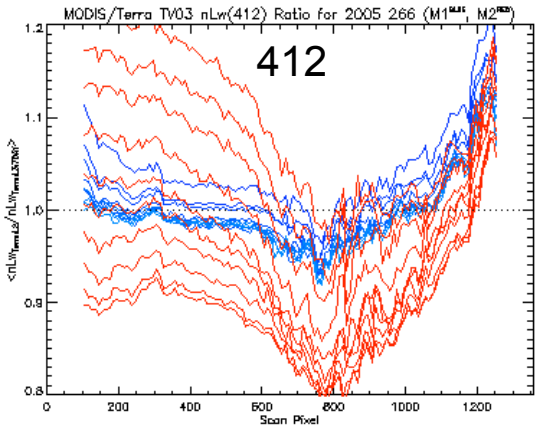


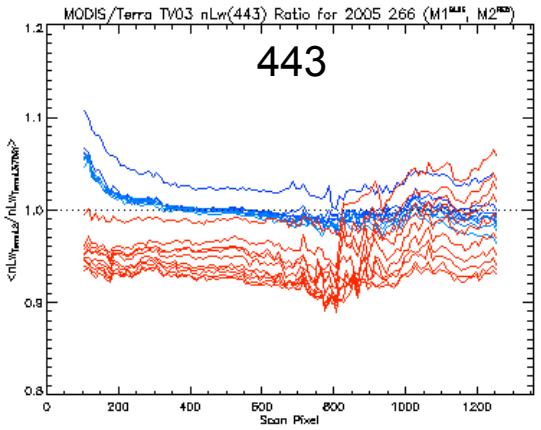
MODIS-Terra Scan-Dependent Variability in nLw

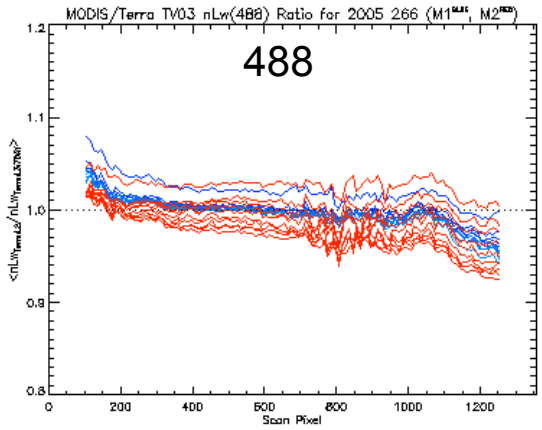
Before Vicarious Characterization

+20%

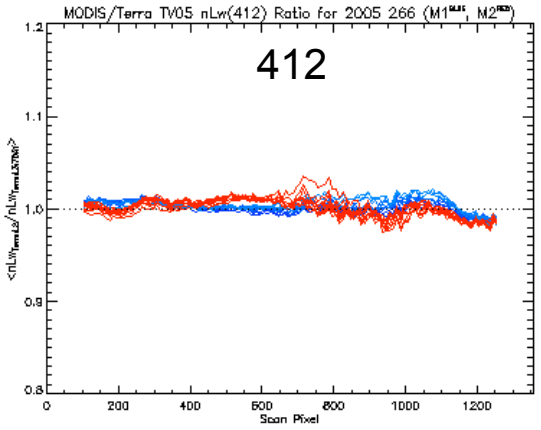
-20%

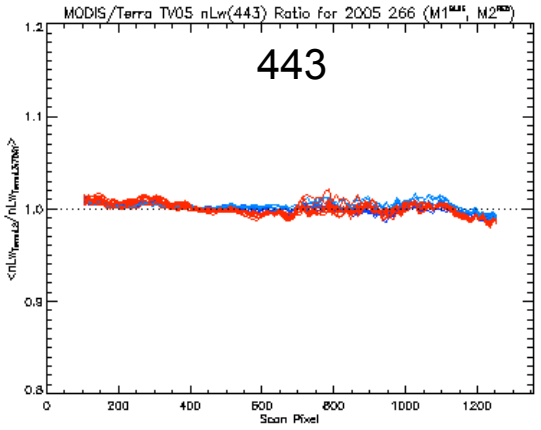


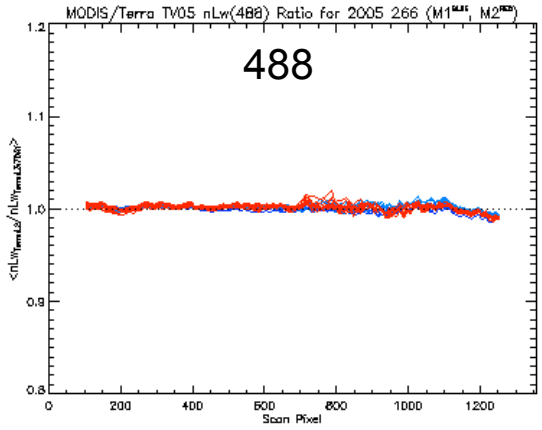




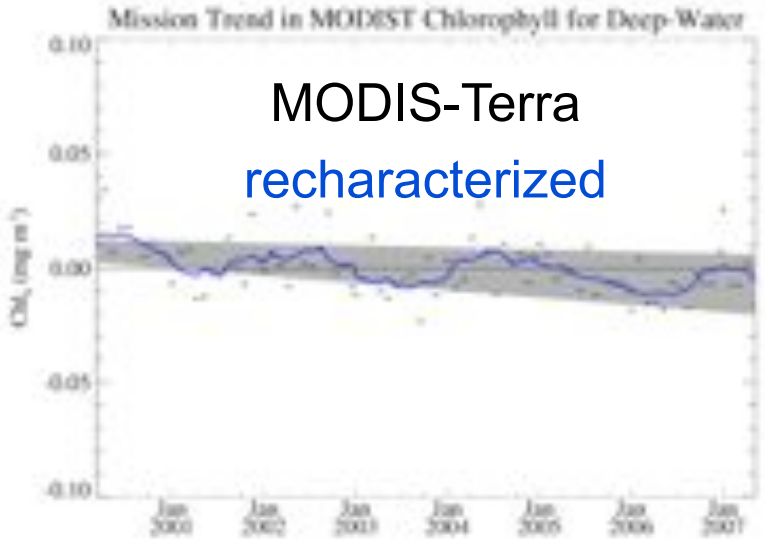
After Vicarious Characterization

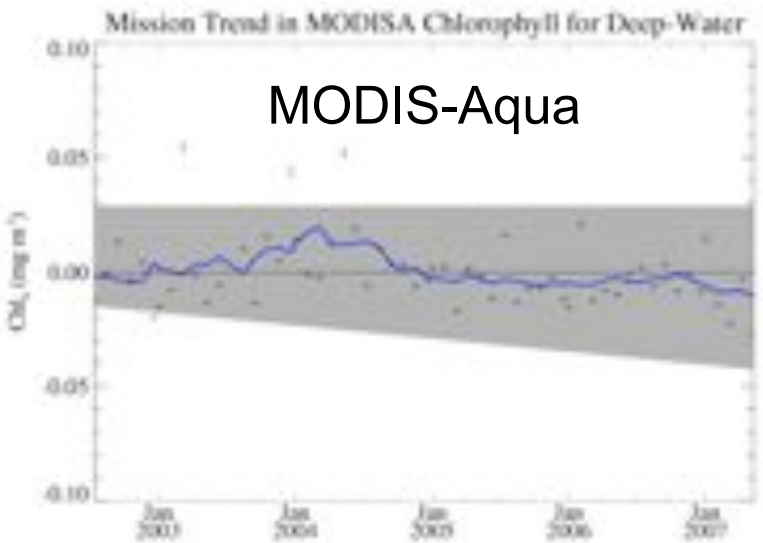


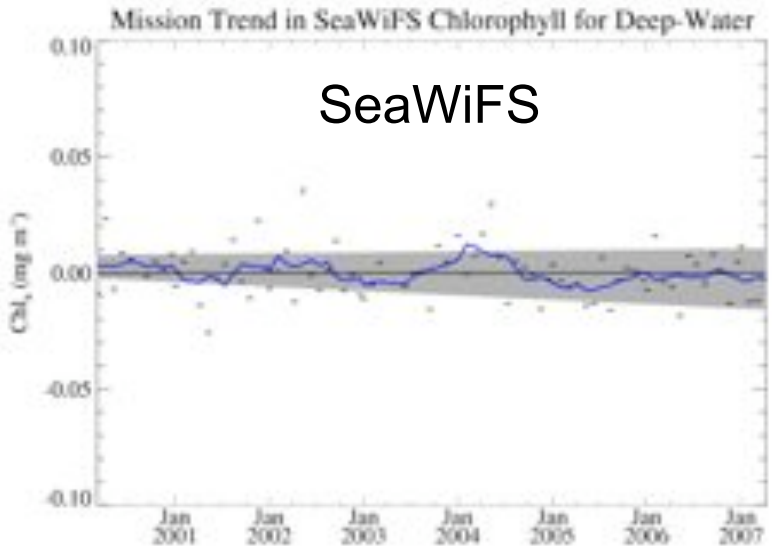


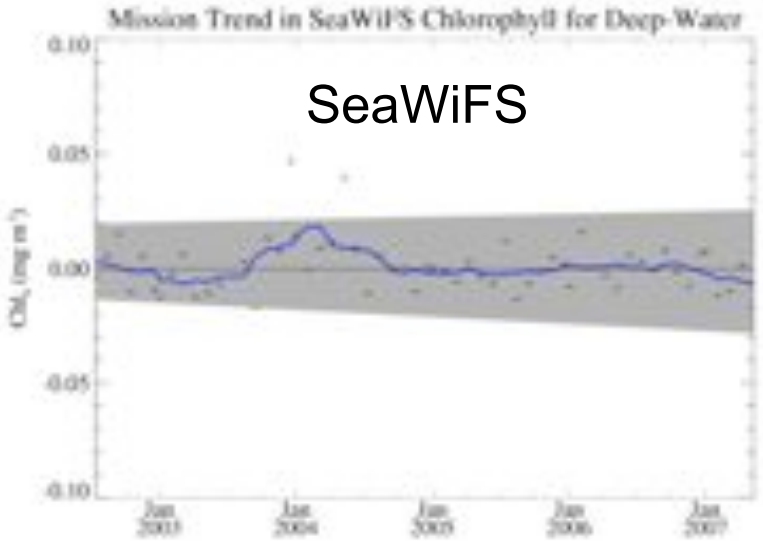


Deep-Water Seasonal Anomaly in Chlorophyll



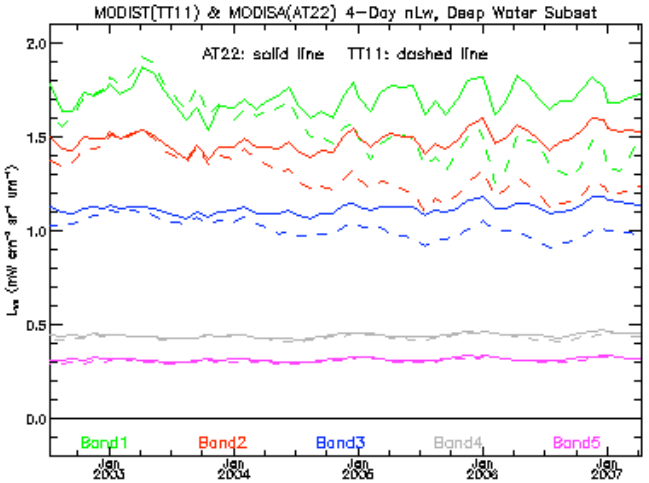


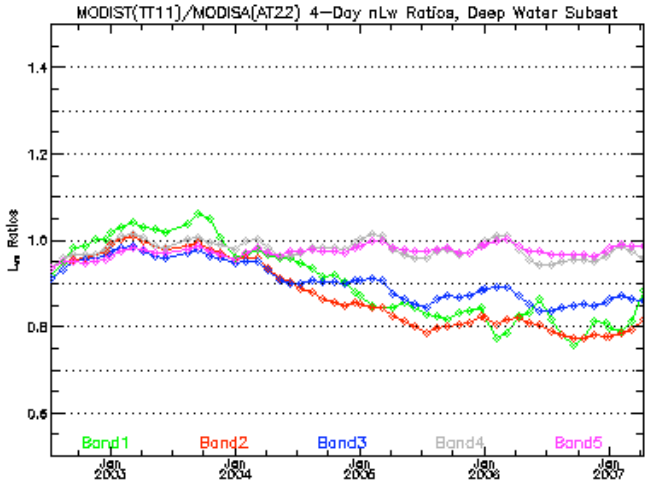




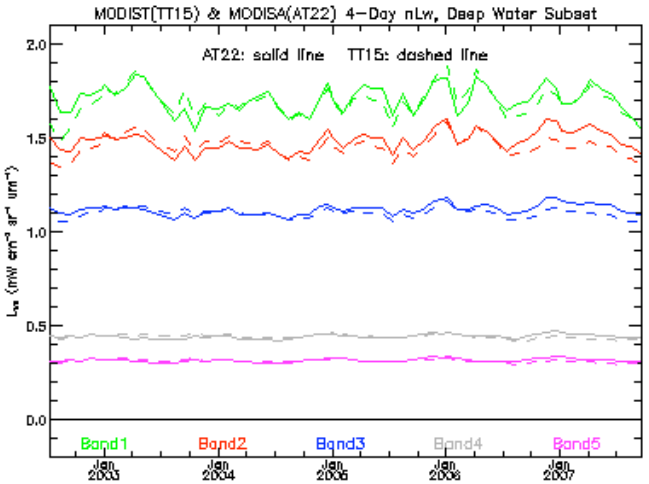
MODIS-Terra and MODIS-Aqua nLw

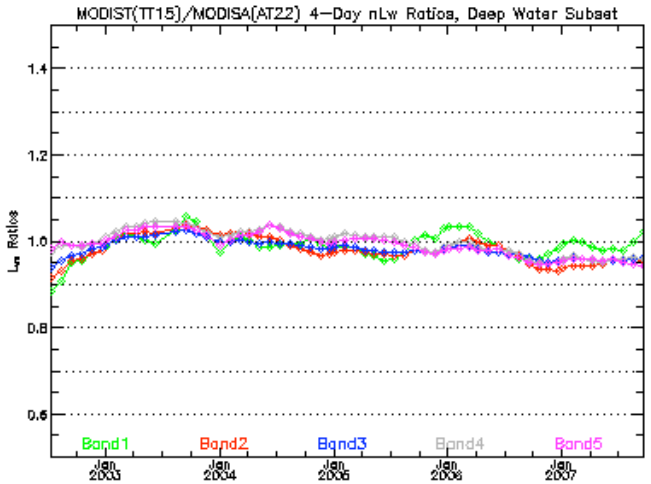
Before Vicarious Characterization





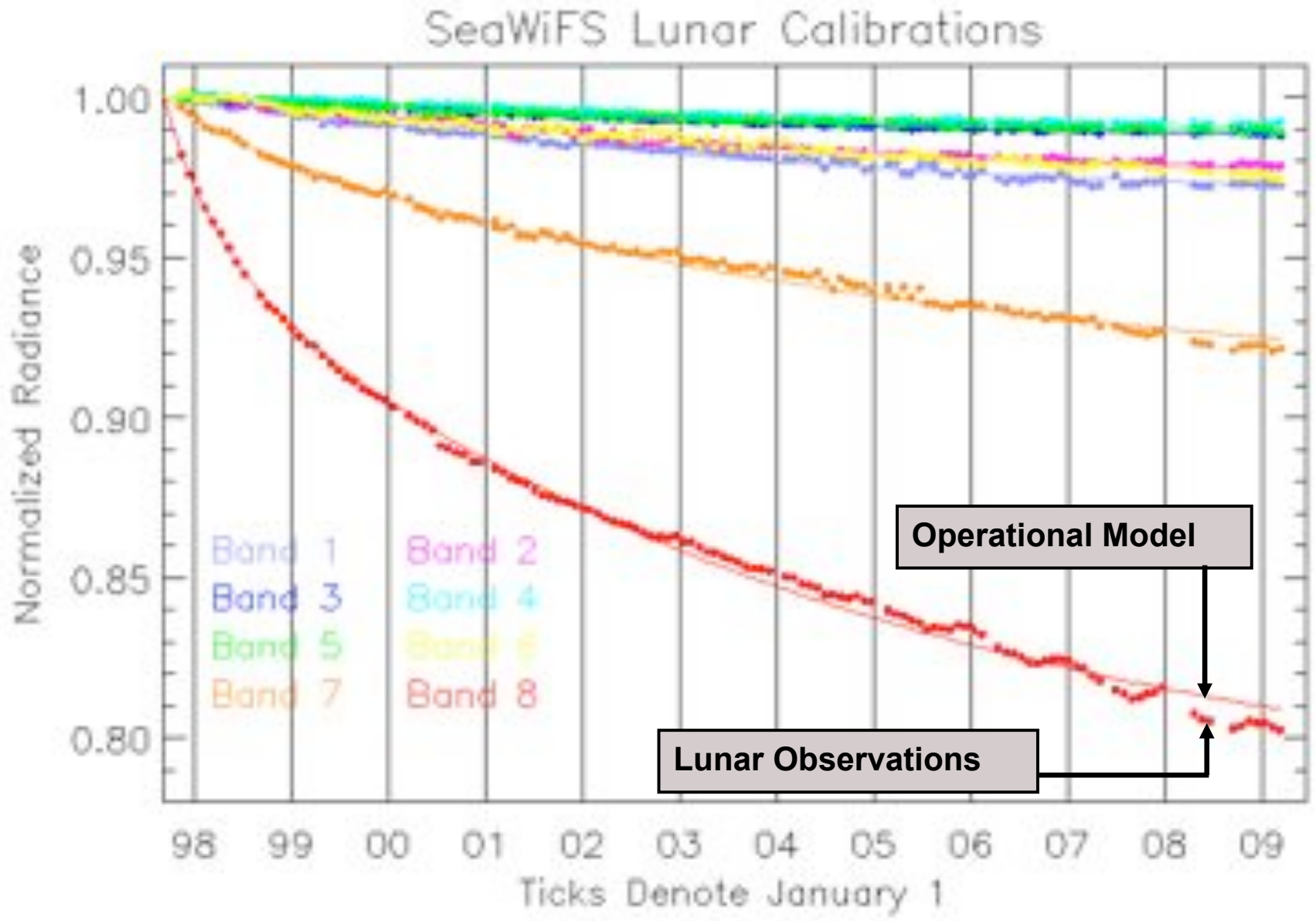
After Vicarious Characterization



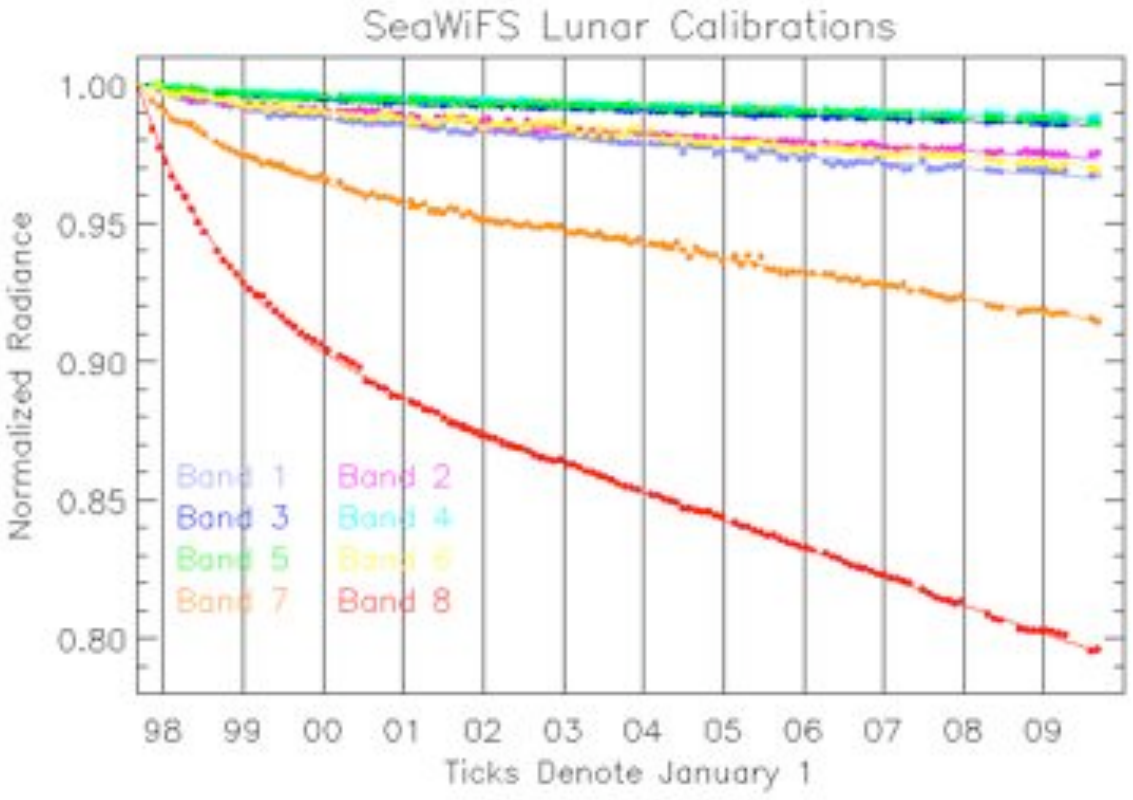


SeaWiFS Calibration Changes

SeaWiFS Lunar Calibration – Before R2009



Improved SeaWiFS Instrument Calibration

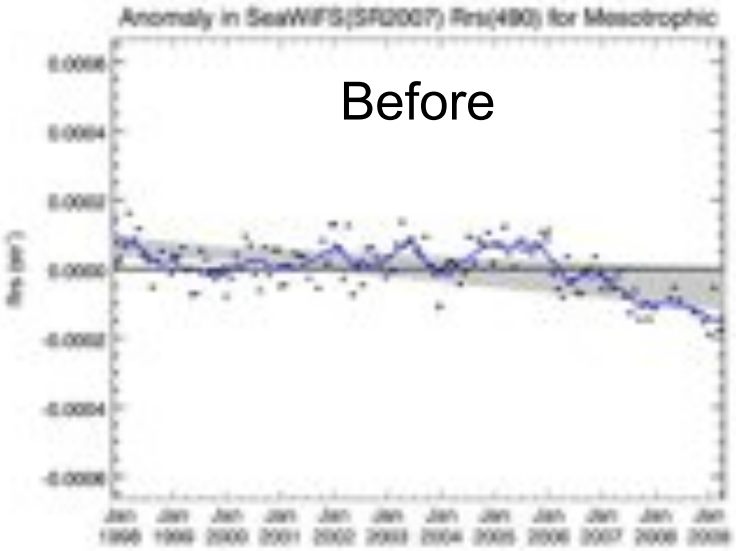


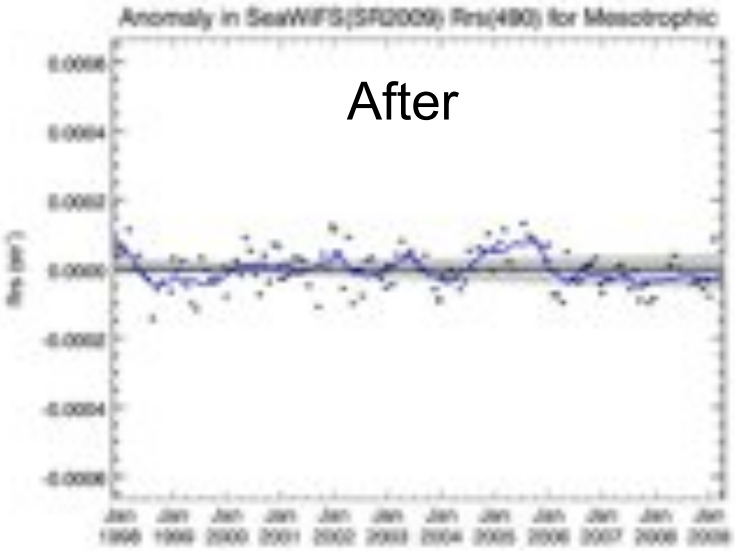
- updated temporal degradation model as derived from lunar cal
  - full mission time-series refit with single exponential + linear model
  - improved knowledge of lunar-view to earth-view gain ratios
- revised temperature corrections
- revert to original prelaunch gains

Impact of SeaWIFS Instrument Calibration Update

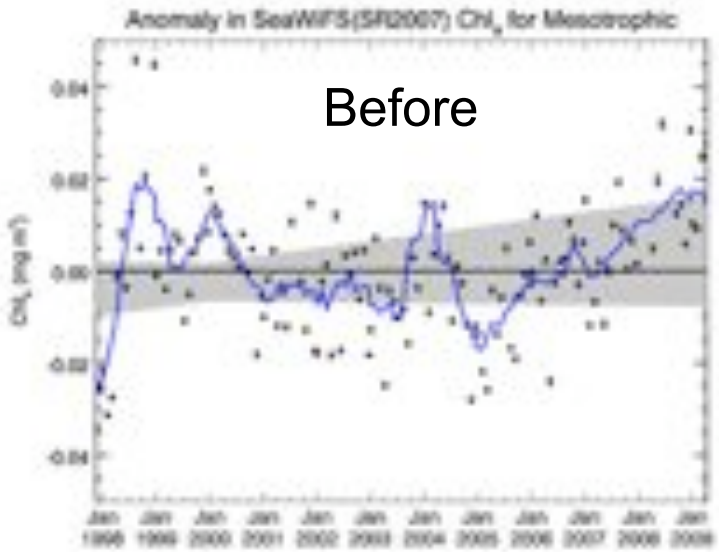
Anomaly Relative to Mesotrophic Mean Seasonal Cycle

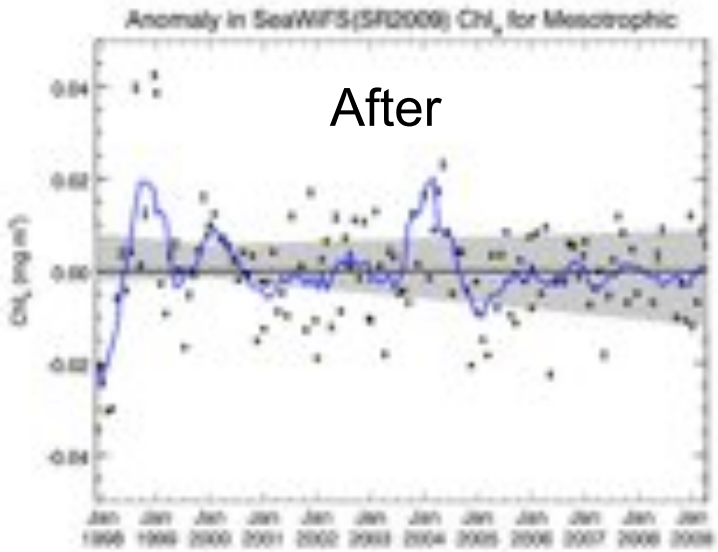
Rrs(490)





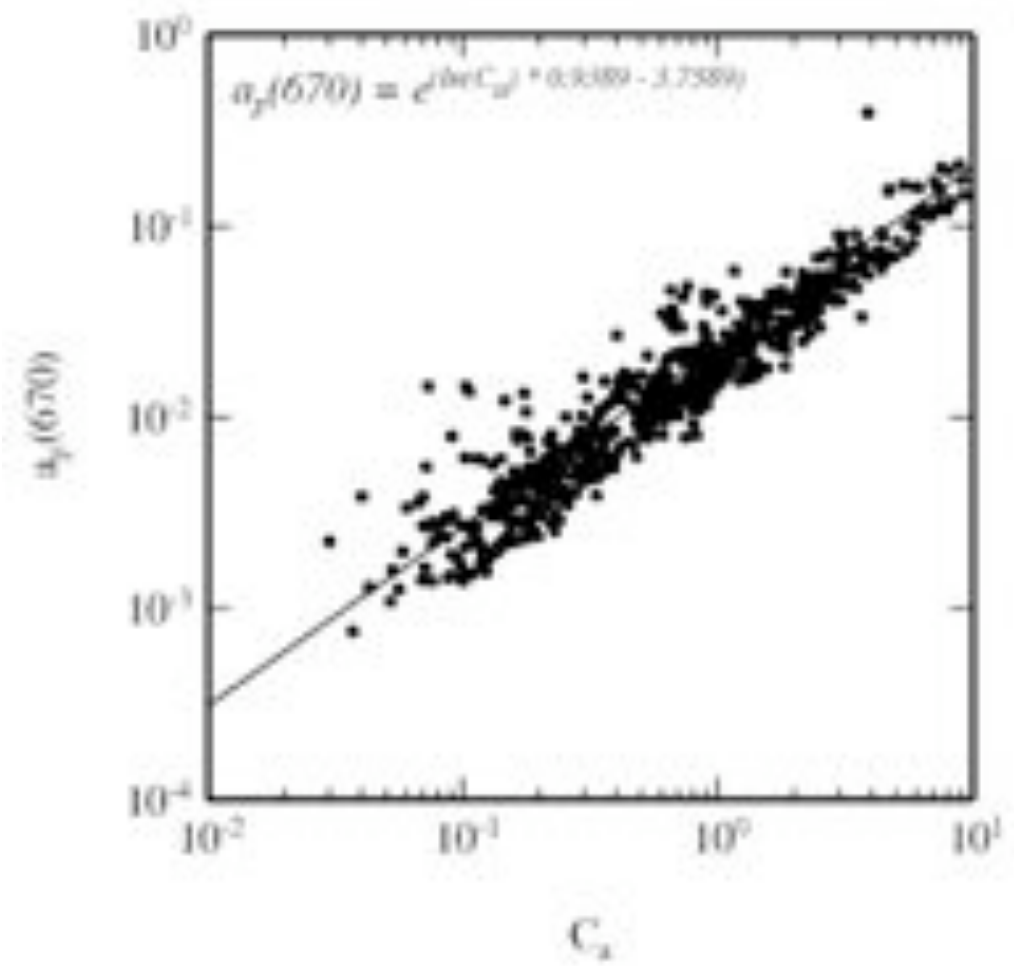
Chl_a



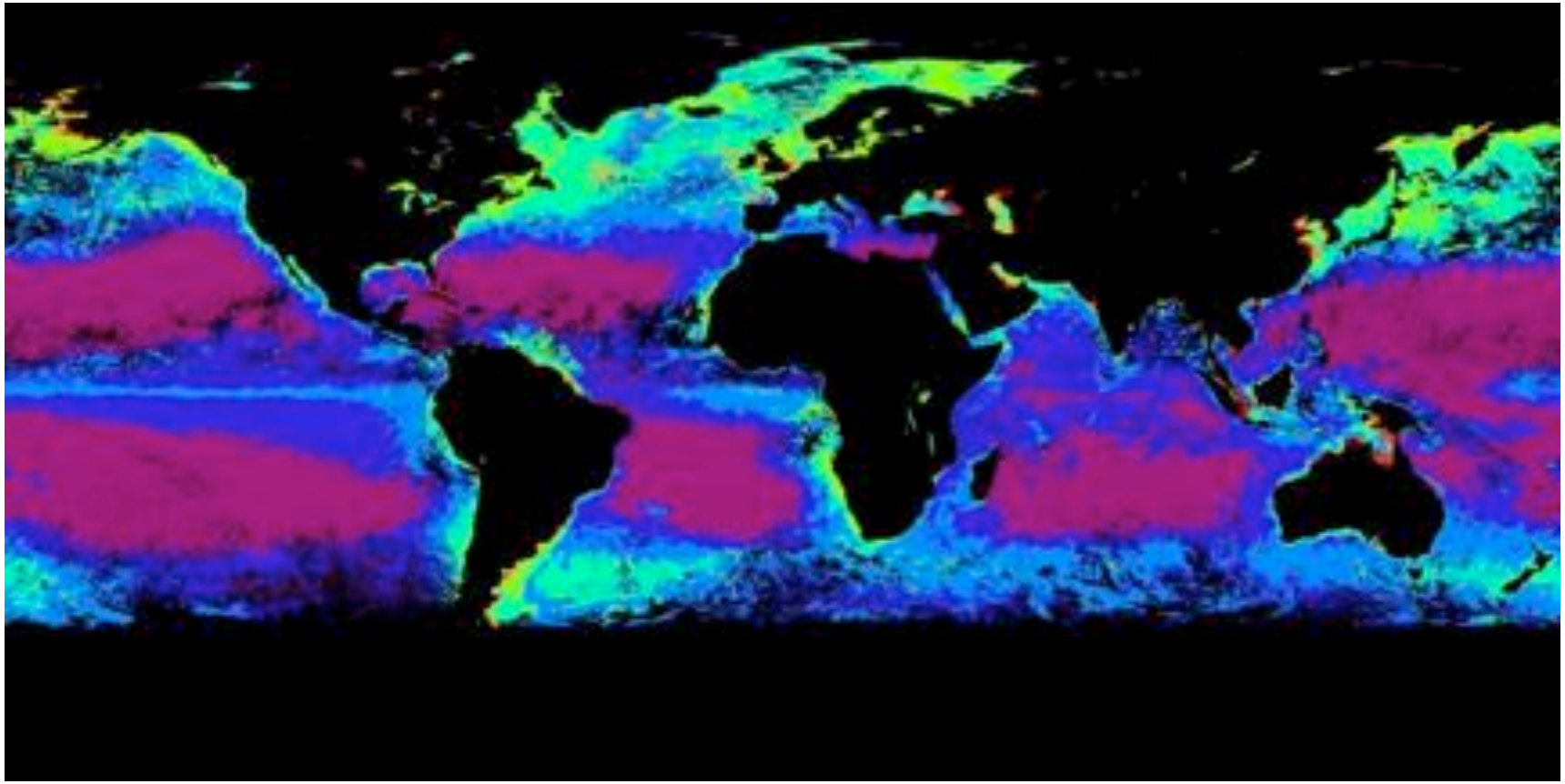


Lw(NIR)

$a_{pg}(670)$ vs Chl_a from NOMAD V2



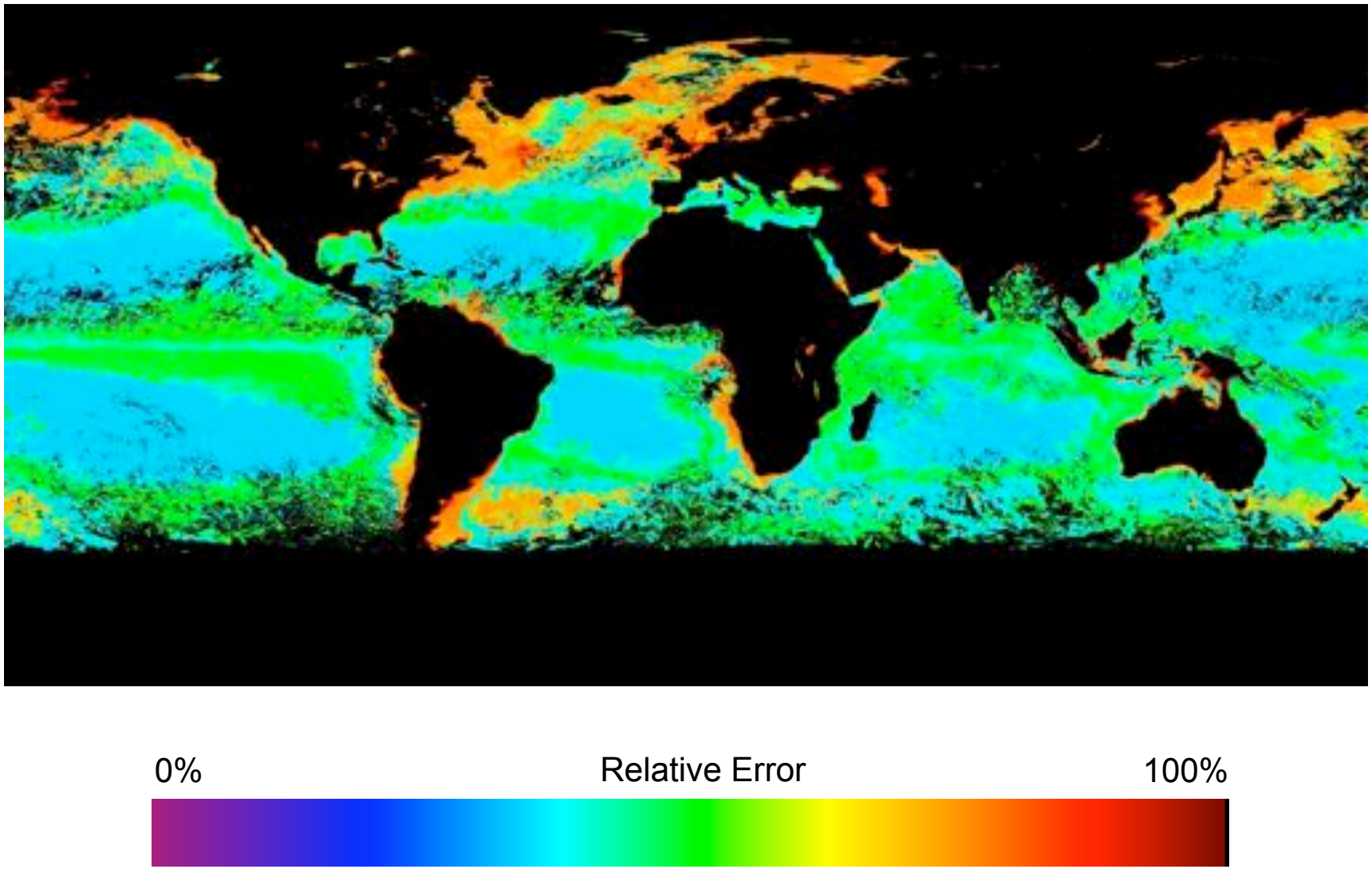
Optical Water Types



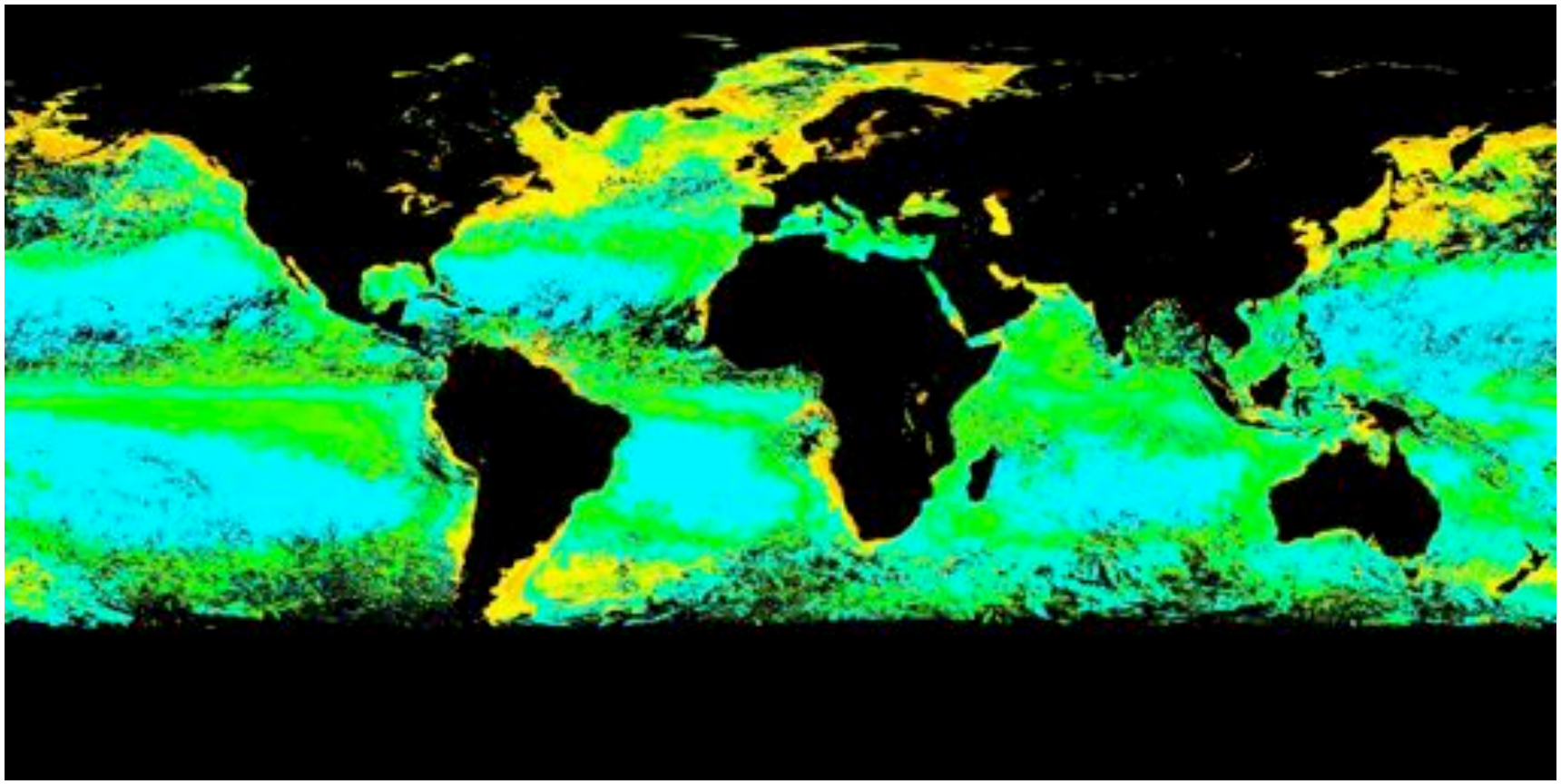
1 Dominant Optical Water Type 8

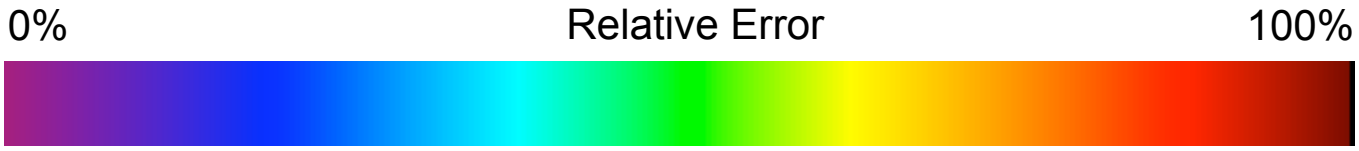
Moore, T.S., et al., A class-based approach to characterizing and mapping the uncertainty of the MODIS ocean chlorophyll product, Remote Sensing of Environment (2009),

Chlorophyll Error – Before Revised Lw(NIR) Model



Chlorophyll Error – After Revised Lw(NIR) Model





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Werdell, P.J., S.W. Bailey, B.A. Franz, L,W. Harding Jr., G.C. Feldman, C.R. McClain (2009). Regional and seasonal variability of chlorophyll-a in Chesapeake Bay as observed by SeaWiFS and MODIS-Aqua, Rem. Sens. Env., 113(6), 1319-1330

Behrenfeld, M.J., T.K. Westberry, E.S. Boss, R.T. O'Malley, D.A. Siegel, J.D. Wiggert, B.A. Franz, C.R. McClain, G.C. Feldman, S.C. Doney, J.K. Moore, G. Dall'Olmo, A. J. Milligan, I. Lima, and N. Mahowald (2009). Satellite detected fluorescence reveals global physiology of ocean phytoplankton, Biogeosci., 6, 779-794.

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Franz, B.A., E.J. Kwiatkowska, G. Meister, and C. McClain (2008). Moderate Resolution Imaging Spectroradiometer on Terra: limitations for ocean color applications, J. Appl. Rem. Sens., 2, 023525.

Stramski. D., R.A. Reynolds, M. Babin, S. Kaczmarek, M.R. Lewis, R. RÃ¶ttgers, A. Sciandra, M. Stramska, M.S. Twardowski, B.A. Franz, and H. Claustre (2008). Relationships between the surface concentration of particulate organic carbon and optical properties in the eastern South Pacific and eastern Atlantic Oceans, Biogeosci., 5, 171-201.

Ahmad, Z., C.R. McClain, J.R. Herman, B.A. Franz, E.J. Kwiatkowska, W.D. Robinson, E.J. Buscela, and M. Tzortziou (2007). Atmospheric correction for NO2 absorption in retrieving water-leaving reflectances from SeaWiFS and MODIS measurements, Appl. Opt., 46 (22).

Frouin, R., B.A. Franz, and J. Werdell, 2003: The SeaWiFS PAR Product. In: Patt, F.S. et al., Algorithm Updates for the Fourth SeaWiFS Data Reprocessing, NASA Tech. Memo. 2003-206892, Vol. 22, Hooker and Firestone, Eds., NASA GSFC, Maryland.

Bailey, S.W.., Franz, B.A., and Werdell, P.J. (2010). Estimation of near-infrared water leaving reflectance for satellite ocean color data processing, Opt. Exp., submitted.

Morel, A. and B. Gentili (2009). A simple band ratio technique to quantify the colored dissolved and detrital organic material from ocean color remotely sensed data, Rem. Sens. Env., 113 (2009) 998–1011.